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Impact on the aquatic ecosystem by mining in the Mike Horse area, Heddleston Mining District, Lewis and Clark County, Montana

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IMPACT ON THE AQUATIC ECOSYSTEM BY MINING IN THE MIKE HORSE AREA, HEDDLESTON MINING DISTRICT, LEWIS AND CLARK COUNTY, MONTANA

By

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Eight stations in the headwater tributaries of the Blackfoot River, Anaconda and Beartrap Creeks, were studied from May through September, 1977, to determine the effects on the aquatic community from acid mine drainage from the Mike Horse Mine, a lead-copper mine, abandoned since 1964. Emphasis centered on water quality, benthic algal species, primary productivity, and benthic macroinvertebrate species diversity. A major objective was to determine which consequence of acid mine drainage-the increased dissolved metals, the ferric hydroxide precipitate, or the lowered pH-had the controlling effect on the aquatic community.

The Mike Horse Mine was the only detectable source of acid mine pollution in the headwater area. Total hardness, specific conductivity, sulfate, and dissolved and total arsenic, cadmium, copper, iron, and zinc were higher at the polluted stations. These concentrations decreased as distance from the mine increased. Dissolved zinc and total iron were the metals found in highest concentrations at the polluted sites. These concentrations were above suggested limits recommended for fish and other aquatic life. pH was not significantly altered by the mine drainage.

Stations up to 0.6 km below the mine were essentially devoid of an aquatic community. As dilution of the mine waters occurred further downstream, the filamentous Chlorophytes were common within the iron precipitate. The algal species were grouped into six categories according to their resistance to zinc and iron.

Primary productivity of the streams increased as distance from the mine increased. Primary productivity at the furthest downstream polluted station (2.4 km) was greater that the productivity of the control stream. Diversity of algal species was controlled by dissolved metal concentrations while density was correlated with the ferric hydroxide precipitate.

Essentially, there was no apparent recovery of the benthic macroinvertebrate community up to 2.4 km below the mine. The number of species and individuals did increase, however, as distance from the mine increased. Species of Chironomidae were found at the downstream polluted station but in extremely low populations that may have been caused by drift.

Dissolved zinc and total iron were the two parameters most positively correlated with the decrease in productivity and diversity of the headwater streams of the Blackfoot River. The question of which of these factors is controlling the secondary productivity is academic, since, with proper mine reclamation, both of these negative impacts would be eliminated.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

Hard rock mining has made a substantial contribution to the economic development of western Montana. From the first miners heading west to pan for gold in the clear running streams of the Rocky Mountains, to Marcus Daly and his Copper Capital, Butte, hard rock mining contributes $144,570,000 to the economy of Montana as of 1976 (U.S. Department of the Interior, 1978).

Mining and its accompanying pollution went unchecked for most of Montana's history. Reclamation of hard rock mining areas was not enforced until 1974 when the State enacted SB 94, the Montana Strip Mine and Reclamation Act.

This study examines the Upper Blackfoot River and its headwater tributaries, Anaconda Creek and Beartrap Creek. A six year study of the Blackfoot River system by the Montana Fish and Game Department began in 1968 (Spence, 1975). The purpose was to gather baseline data prior to a proposed open pit mining operation in the upper river area announced by the Anaconda Company in 1970 (Spence, 1975). Acid mine drainage from the abandoned Mike Horse Mine and other shafts in the headwater area were recognized by that study but only information concerning the chemical characteristics of these shafts was collected. It was suggested that a detailed "chemical and biological study of the Blackfoot River and its tributaries affected by mine drainage...(be done)... to determine existing problem areas, what factors are depressing aquatic life, where the recovery zones are, and what causes the recovery..." (Spence, 1975).

History of the Mike Horse Mine

The Mike Horse Mine is located in the Heddleston mining district. and was originally the property of Sterling Mining and Milling Company. It was discovered by Joseph Heitmiller in 1898. In the next 15 years, only development work was accomplished due to unsuitable roads and little ore was exported during this time. In 1919, a mill was put into operation in the Mike Horse valley and the years between 1923 and 1924 were very productive (Pardee and Schrader, 1933). During the next 40 years of sporadic production by American Smelting and Refining Company (ASARCO), the Mike Horse mine produced 13,172 metric tonnes of concentrate bearing 3,124.8 g of gold, 6,575 kg of silver, 4,499,342 kg of lead, and 197,662 kg of copper (personal memo S.M. Lane, 1977). The area is presently leased to Anaconda Company by ASARCO (personal memo S.H. Huff, 1978).

The underground workings included three adits with most of the veins being oxidized to depths ranging from 15-30 meters. In these zones iron oxides were the most abundant minerals (Pardee and Schrader, 1933). Although a few small prospectors are actively mining in the area today, these activities have no effect on the streams under study.

General Description of the Study Area

The Blackfoot River originates near the continental divide, southwest of Rogers Pass and 30 km southeast of Lincoln, Montana in Lewis and Clark County. The headwater area is more specifically located in Township 15 N, Range 6W in sections 22,23,26,27 and 28 (Figure 1).

Tepee Lodge Creek is the major tributary of Anaconda Creek, originating from springs along the continental divide. The elevation of these springs is approximately 1890 m. It flows in a westerly direction seeping into and out of the alluvium. It is typical of a mountain stream, having a wide diversity of habitat from quiet pools to turbulent riffles. No major mining activity was evident along its course although an abandoned gravel road follows the lower stretches.

Beartrap Creek has been significantly altered in a number of ways. The upper stretch, also originating from springs along the continental divide, was dammed in the 1900's to form a tailing pond for the mining operations in the Mike Horse area. The channel below the dam received massive habitat destruction during a dam breakage in 1975 and through its subsequent rebuilding. This constitutes a 457 m stretch below the dam and before the confluence with the Mike Horse Creek. At this confluence, the Beartrap Creek flows 1.9 km before converging with Anaconda Creek to form the Blackfoot River.

The Mike Horse Creek becomes polluted by acid mine drainage approximately one km below its origin. It runs over fragmented rocks and debris and over an open hillside void of topsoil and terrestrial

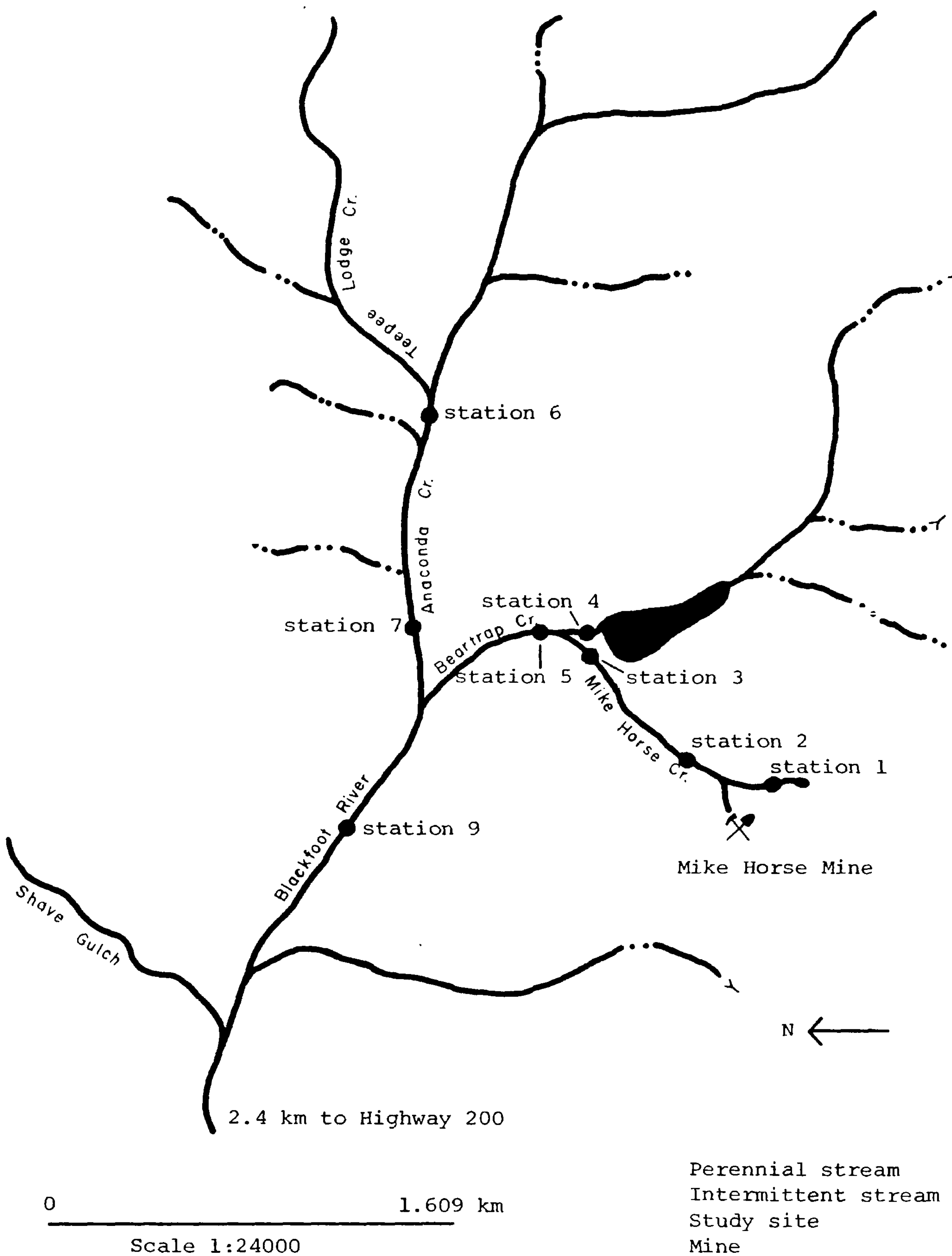


Figure 1. Study Area-Headwaters of the Blackfoot River.

plants. It flows through rusted machinery, gangue, exposed underground mining structures, and deteriorating buildings for approximately one km before converging with the Beartrap Creek.

This region has an average winter temperature of -5°C and a mean summer temperature of 16° C. The average annual precipitation is 50.4 cm, mostly in the form of snow (Coffin and Wilke, 1971). The spring snowmelt accounts for most of the water in the region's peak runoff. The months of July and August are usually dry and during these months water flow is largely dependent on snow water originating in the high mountains (Weisel and Newell, 1970).

Geology

Mountain summits within the headwater area range from 1829 to 2073 meters in elevation. The slopes are steep but not rough and the valleys are narrow and 600 m or more in depth (Pardee and Schrader, 1933). The main summits are flat or gently sloping with remnants of an old surface of small relief that once spread over the general region. It has since been elevated and largely cut away by streams (Pardee and Schrader, 1933).

The Rocky Mountains between Glacier National Park on the north and the Clark Fork and Blackfoot River on the south, were in general, heavily glaciated with several glaciers extending southward into the Blackfoot Valley. The area under study is a glaciated, mountainous region with forest covered slopes, a few cliffs, and rounded crests. The intersections of major valleys with the divide generally are marked by steep slopes, and in places, cliffs which were possibly former glacial cirques. The topography bears little relation to the structure of the underlying rocks of the Precambrian Belt series (Melson, 1969). This 130 km area is underlain by metasedimentary rocks of the Belt series, that have been folded, faulted, and intruded and have been covered in places by extrusive igneous rock or by unconsolidated or semi-solidated sediments and alluvium (Coffin and Wilke, 1971).

The oldest rocks in the area are Belt Series argillites and quartzites or sandstones. Throughout the region they dip very gently northward and, as exposed along the deeper valleys, they have been intruded by diorite which is an intrusive rock composed primarily of feldspar and hornblende (Alden, 1953). The diorite shows a noticeable alteration to a soft light gray material sprinkled with pyrite grains. Much additional pyrite was introduced along joint and seams, with the result that more than half of the weight of large masses of the gangue from mining is pyrite (Pardee and Schrader, 1933).

After the wall rock had been altered and pyritized, the following minerals were introduced into the veins: pyrite, galena, sphalerite, chalcopyrite, arsenopyrite, quartz and a mixed carbonate of calcium, magnesium, manganese, and iron (Pardee and Schrader, 1933). Pyrite galena, and sphalerite formed the bulk of the ore in the Mike Horse vein. They were followed and replaced to some extent by a second generation of minerals which included the copper-bearing sulfides (Pardee and Schrader, 1933).

Rationale

The first objective of this study was to examine the chemical, physical, and biological parameters of the streams. The information collected was used to determine the effect of acid mine drainage on the aquatic community. The rationale for the use of biological criteria, in addition to the chemical and physical parameters, was based on the assumption that effluents produce distinct and measurable effects on organisms or groups of organisms over a period of time (Patrick, 1970). These changes may not be detected by chemical analysis if the pollution occurs sporadically and then disappears. Healthy streams exhibit a high index of diversity. The effect of pollution is to decrease the number of species and to greatly increase the abundance of a few tolerant species which become extremely common.

The primary producers were chosen to evaluate the levels of ecological stress because they most clearly reflect the chemical changes in the water due to their rapid mineral uptake. Considerable information exists concerning tolerance of various algal species and their differential sensitivity to environmental conditions (Patrick, 1964). Benthic algal species are reliable indicators of water quality if growth occurs under the influence of a pollutant (Williams, 1964).

Aquatic macroinvertebrates are used as indicators of water quality due to their specific habitat preference, low mobility, central position in the food chain, and their long life histories (Mackenthum, 1966; Hynes, 1970). Hynes (1963) stated that when pollution is fairly severe the effects on most invertebrates are so marked that whole taxonomic groups are affected. Actual specific differences become important only when pollution is very mild.

Mines may have long term effects on aquatic communities if they are not reclaimed and allowed to contribute toxic effluents to watersheds. These discharges are related to coal, zinc, copper, or other metal mines when sulfurous minerals are oxidized:

$$FeS_2 + 3\frac{3}{4}\,O_2 + 3\tfrac{1}{2}\,H_2O \longrightarrow FeOH_3 + 4H^+ + 2SO_4^{-2}$$

(Stumm and Morgan, 1970).

This results in a low pH, toxic concentrations of dissolved metals and the precipitation of iron compounds. This not only destroys the aesthetic value of streams and rivers but also creates a toxic and uninhabitable environment for aquatic life. These toxins will either eliminate or severely reduce the biota to a few tolerant species until dilution, dissipation, or volatilization reduces the concentrations to acceptable levels.

It is not clearly understood which of these resulting factors - the low pH, the toxic concentrations of metals, or the iron precipitate - are responsible for the reduced or eliminated biota in acid mine streams.

Alone, pH reveals little of the chemistry of the water while some dissolved elements are known to be directly toxic to aquatic life (Wentz, 1974). Warner (1971), in a study of acid mine waters in Ohio, concluded that the toxicity of mine waters to aquatic organisms is a function of more than one factor. The increase in concentrations of dissociated H^+ and sulfate ions, an increase in osmotic pressure caused by high concentrations of mineral salts, an increase in CO_2 tensions resulting from low pH values, oxygen reduction by the oxidation of metals, and possible synergism of metallic cations, all may contribute to the toxicity of mine waters. Whitford (1959), while recognizing that pH alone cannot be used to indicate the type of flora in acid mine waters, believes it is still the best indicator due to its effect on the solubility of metals. Bennett (1969), in a floristic study of acid mine waters, concluded that total acidity, not pH, was the controlling factor. He found reduction in the number of algal species when acidity increased but pH remained the same.

Hynes (1970), in contrast, concluded the presence of the iron hydroxide precipitate and the resulting oxygen deficiency caused by oxidation of ferrous iron were at least as important in eliminating species as was low pH. Dills and Rogers (1974) agree with Hynes concerning pH but added the ionic solutes may also influence the biological community. Vandenberg (1974) reported a reduced macroinvertebrate population in streams affected by iron precipitate and high concentrations of dissolved metals but with a pH above 6.0.

The second objective of this study was to delineate which changes in the aquatic community were caused by the lowered pH, the increase in dissolved metals, and the coating of the bottom by the ferric hydroxide precipitate. Particular interest was given to the effects of dilution on the aquatic biota as clean waters converged with the acid waters from the Mike Horse Creek.

CHAPTER II

MATERIALS AND METHODS

Field collection for this study was conducted over a five month period, from May to October 1977.

Primary Productivity

The glass plate method was used to evaluate primary productivity. This method bases primary productivity on chlorophyll content, a function of photosynthesis, and dry and ash-free weight, a measure of standing crop.

Thirty-four 10 x 10 cm smooth, clear glass plates were glued to river bed rocks. Duplicate plates were placed at specified points in the streams (Figure 2), corresponding to the nine stations used for water analysis and insect collection. These points were chosen for their similarity in current velocity and radiant energy.

The material was scraped from each plate and rinsed into a polyethylene bottle with 90% v/v acetone. The samples were immediately placed on ice in darkness until they were returned to the lab for analysis. Each sample was brought to a known volume with 90% v/v acetone and allowed to extract for 24 hours at 4°C in darkness. Each sample was centrifuged for 20 minutes at 500 G and the optical density at 663, 645, 630 and 710 nm was recorded using a Shimadzu MPS 50L Recording Spectrophotometer. The concentration in milligrams of chlorophyll _a_, _b_, and _c_ per sample was

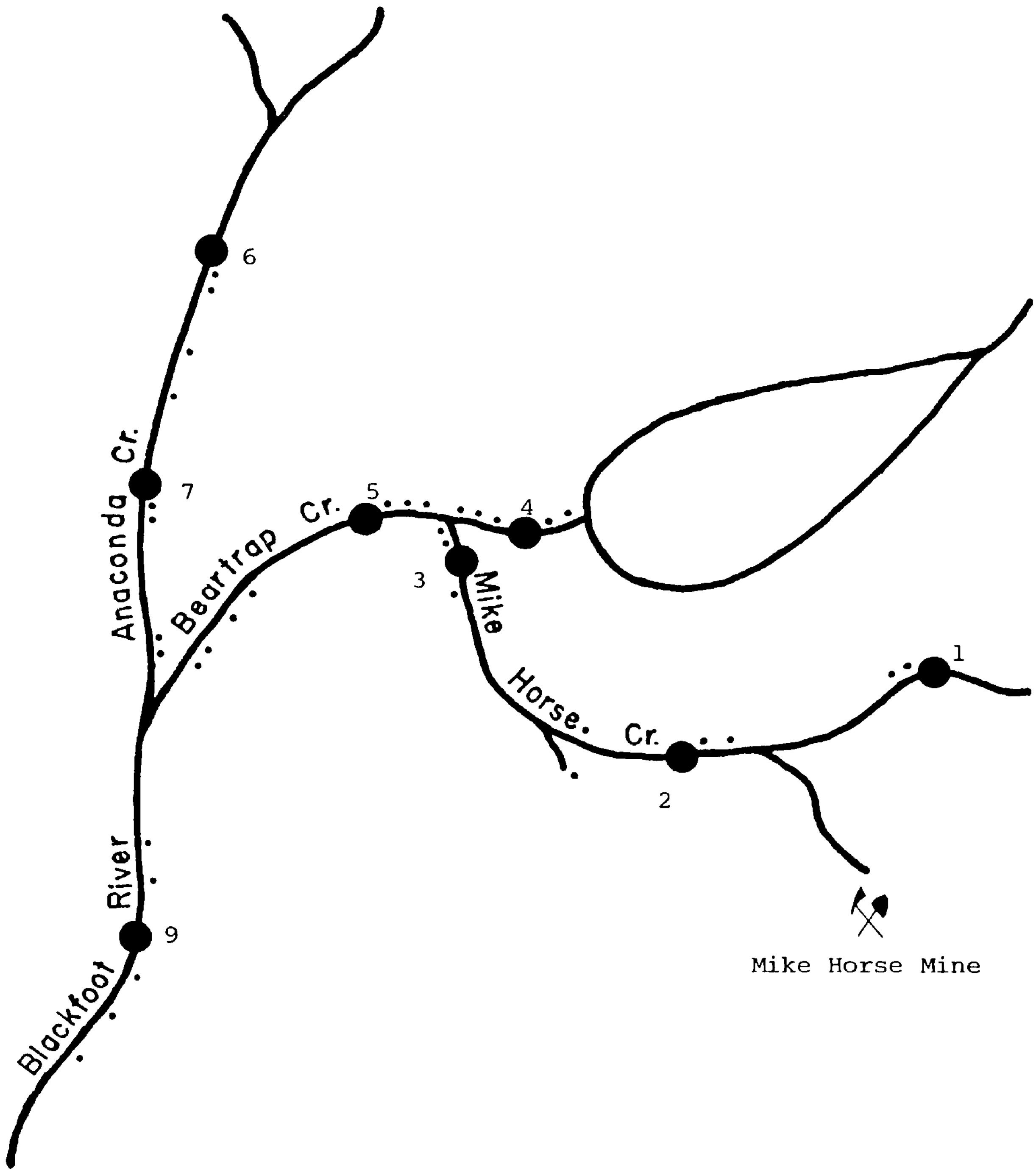


Figure 2. Stations for water analysis and insect collection and placement of glass plates for primary productivity(signified by small dots).

calculated by the equation outlined in Standard Methods (1977). Primary productivity was sampled three times during the study period, in June, July, and September.

Dry and ash-free weight were determined for each sample using the procedure outlined in Standard Methods (1977).

The plates were submerged for four weeks during each sampling period. Waters (1961) found a submergence period of four weeks caused saturation but chlorophyll a content remained at the same level up to ten weeks during the summer months. Marcus (1977), in similar experiments, found the organic standing crop peaked on day 35 of exposure, whereas chlorophyll a density continued to increase through a 60 day period. Peak productivity ranged in exposure time from 28-35 days. Incubation periods of a longer or shorter duration tended to provide values of a smaller magnitude.

In comparing various artificial substrates, Patrick (1963) found glass not to be selective within the diatom group. Cook (1956) reviewed the colonization of artificial substrates and concluded there is no universal substrate to obtain all organisms of a habitat. In seawater, attachment and production on smooth glass, frosted glass, smooth plexiglass, and frosted plexiglass were compared with no significant differences. Black-backed, white-backed, and clear plates were also compared showing similar results (Castenholz, 1961). In lakes, horizontal plates invariably supported seven times more material than vertical plates (Newcombe, 1950). Hohn and Hellerman (1963) concluded styrofoam supported a representative diatom sample regardless of temperature or current, while glass was less reliable in relatively low temperatures and fast current. Glass was found to be as good as styrofoam at summer temperatures and comparatively slow current velocities. Grazing, peeling, sloughing off, and turnover are probably the greatest sources of error when measuring primary productivity by the glass plate method.

When placed on the stream bottom, an artificial substrate is an empty habitat subject to colonization. The chlorophyll content and photosynthetic capacity measured may be a function of age of the periphytic population as well as a function of the environment. They may not reflect the same relationship to external factors as those on a natural substrate (Waters, 1961). Mackenthum (1969) states the quantity of algae may not be directly related to chlorophyll content. Large quantities of algae may be present but not growing or a small population of algae may exhibit a substantial growth rate.

The glass plate method is adaptable to running water habitats while other methods used to measure primary productivity in lakes cannot be adapted to use in flowing waters. The light and dark bottle method and the C_{14} method both require containment of the water for analysis. Due to physiological algal adaptation to flowing water, photosynthesis is reduced when specimens are placed in standing waters. In small streams, the diurnal pulse in dissolved oxygen is caused primarily by changes in the saturation value related to diurnal temperature changes. It is not a function of accumulation and depletion of photosynthetic oxygen (McConnell and Sigler, 1959).

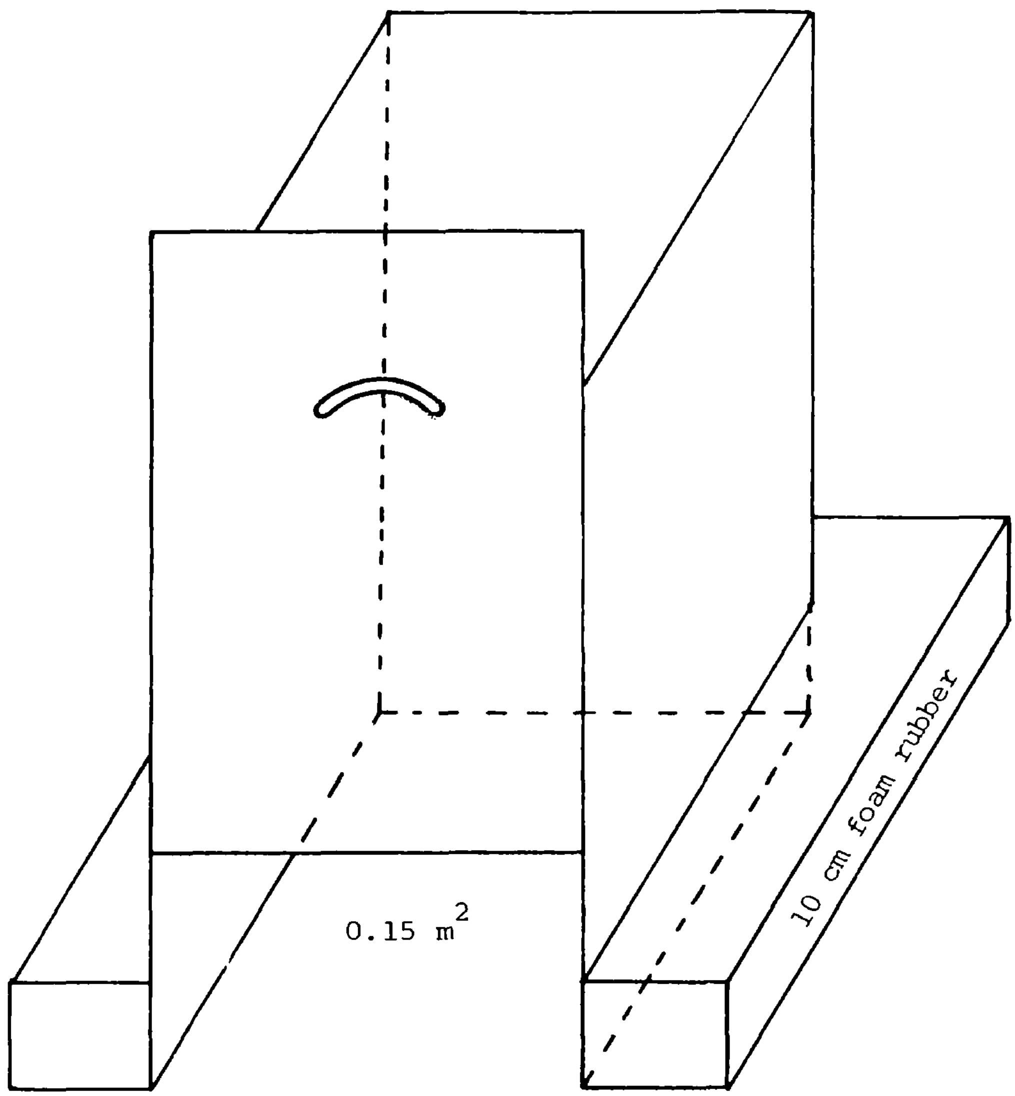
An algal species checklist was made for each station. Specimens were scraped from natural substrate at the stations and keyed to species when possible. A Wild phase microscope was used for this identification. Patrick and Reimer (1966 and 1975), Prescott (1962 and 1970), and Smith (1942 and 1950) were the taxonomic keys used to identify the benthic algae species.

Macroinvertebrates

A 0.15 m^2 coarse-meshed box sampler was used to collect benthic macroinvertebrates at the eight stations. Two samples were taken at each station in May, June, and July. These sampling stations were in the same location as the water quality stations (Figure 2).

The box sampler's door, sides, and flange were constructed of sheet metal (Figure 3). The sampling area was surrounded by a 25 cm flange to which a 10 cm thick layer of foam rubber was attached. This created a seal to the substratum, preventing the loss of insects from the sides and the ends. This is the major advantage of the box sampler over other samplers that delineate their sampling area by a one dimensional wire frame. The mesh size of the net was eight threads per centimeter, preventing an accurate sampling of insects in early instars. All samples were taken from riffle areas having similar substrate, current velocity, and depth.

The results from the two monthly samples at each station were combined to form one composite sample. From this sample, percent composition and species diversity indices were calculated. In a study done by Needham and Usinger (1956) of a single uniform riffle,



Scale: 2.4 cm = 0.3 m

Figure 3. Box Sampler used for collection of Macroinvertebrates.

they concluded that 73 samples would be required to give significant figures (95% level of confidence) for total numbers of aquatic insects. It was further concluded that two or three samples from one riffle would be sufficient to insure that at least one representative of the most common genera would be present.

The insects were hand picked from the net in the field and placed in a 10% formalin solution. Upon returning to the lab, the samples were sorted, counted, and identified to genera and species when possible. Identification was accomplished with the aid of a Bausch and Lombe variable power (7-30) dissecting scope. Taxonomic keys of Usinger (1966), Edmunson (1959), and Hilsenhoff (1975) were used for identification.

The Shannon-Weaver index of diversity was used to determine species diversity: $d = -\Sigma[P_i \cdot \log_e)P_i]$ (Shannon and Weaver, 1963), where P_i is the number of individuals in one species divided by the total number of individuals. This index is a dominance diversity indice, measuring not only the richness in terms of numbers of species in the area but how equally the individuals are distributed among the species. The more equal the distribution, the greater the diversity (Wilhm, 1972). It expresses the relative importance of each species collected, not merely the relationship between total numbers of species and individuals. It is also not affected by sample size because the maximum value of $\bar{d}$ depends on number of individuals counted and is obtained when no two individuals belong to the same species.

Physical and chemical parameters. The Montana Department of Fish and Game and the Water Quality Bureau analyzed the water for dissolved and total recoverable arsenic, cadmium, copper, iron, lead, and zonc by Atomic Absorption Spectroscopy. The samples used for dissolved minerals were filtered through a 45 μ Millipore filter in the field and stored in 250 ml polyethylene bottles. Water for total recoverable analysis was collected and stored in 1000 ml bottles. Both samples were preserved in the field with nitric acid.

The following constituents were determined using procedures from Standard Methods (1977): Sulfate-the Gravimetric method, phosphate-the Ascorbic Acid method, and alkalinity. Total hardness was determined by the Hach Direct Reading Engineers Laboratory, Model DR-EL. Nitrate concentrations were measured using the Cadmium Reduction Column method and magnesium and calcium were detected by Atomic Absorption Spectroscopy (EPA Manual of Methods, 1974).

Chemtrix field meters were used to determine pH, specific conductivity, and dissolved oxygen. The water temperature at each station was measured by a hand held partial immersion thermometer (-20 to 110°C $\pm$ 1°). Mean velocity was measured using a Gurley Pygmy current meter. These recordings were used to calculate discharge rates for each station.

General site description information was gathered at each sampling including substrate size, width and depth, complexity of habitat, drainage area, and stream length.

CHAPTER III

SITE DESCRIPTIONS

Sampling Stations

Nine sites were chosen on Anaconda and Beartrap Creeks and the Blackfoot River to determine the effects of acid mine drainage. Station 8, six m above the convergence of Beartrap and Anaconda Creek on Anaconda Creek, was sampled throughout the study. This station became a standing pool in early June and all species unable to survive in standing waters, were eliminated. For this reason, data from this station will not be presented.

The chemical and biological characteristics at the time of sampling are discussed in Chapter IV. The rubble classification established by Cummins (1962) was used to identify substrate.

Site I-Upper Mike Horse Creek

Site 1, draining a 0.39 km^2 area, was located 0.5 km above the Mike Horse Mine on Mike Horse Creek. It was an intermittent stream, receding into the alluvium and returning to the surface 550 m above site 1. By the end of July, a 40 m section below site 1 had also gone below the surface before its confluence with the waters of the Mike Horse Mine.

There was considerable mining activity above site 1 but no mine waters were being discharged from the shafts in the area during the study period. The stream did flow over gangue material left from previous activity.

The creek at site 1 was 1-2 m wide, divided by a narrow mound of substrate. Its depth ranged from 1 to 10 cm. The discharge varied according to the season - 8.55 cubic feet per second (cfs) (.24 cubic meters per second (cms)) in June to 1.27 cfs (.03 cms) in August. The upper limit of the station was characterized by a steeper gradient with the lower reaches slow flowing and shallow. The stream has been altered, resulting in uniformity of habitat. There were a few scattered riffles with relatively low turbulence and no deep pools.

The substrate ranged from gravel (10 mm) to boulder (256 mm) and there was no ferric hydroxide precipitate evident at this station. 60% of the channel was densely covered with long strands of filamentous algae throughout the study period. The stream was bordered with rocks, debris, and snags on the west side and shaded by Lodgepole pine (*Pinus contorta*) and Douglas fir (*Pseudotsuga menziesii*) with an understory of *Ribes sp.*, *Rosa sp.*, and annual herbs and perennial grasses on the east side. There were neither true banks at this station nor well defined channels due to mining activities of the past.

No fish were observed inhabiting the waters at this site. Deer tracks were noticeable along the banks throughout the study period. A Spotted Sandpiper and Pine Siskins were observed drinking from this section of stream.

Site II-Middle Mike Horse Creek

Site 2 was located 0.3 km below the effluent of the Mike Horse mine on Mike Horse Creek and drained a 0.48 km^2 area. There was a heavy ferric hydroxide precipitate throughout the station, depositing approximately 1 cm per month of sediment on the stream bed. The channel was unstable, being altered each year due to heavy erosion on the southeast bank and changes in the amount of stream flow. The waters flow over exposed underground mining structures, tricycles, beds, lamps, and other debris encrusted with the iron precipitate.

The stream was deeper at station 2, ranging in depth from 2 to 16 cm in pools with the width remaining 1-3 m. The discharge varied from 8.3 cfs (0.23 cms) in June to 3.0 cfs (0.085 cms) in August. The current was swift and uniform throughout the station forming several pool areas below small falls created by jams from debris. The substrate, ranging from pebbles (32-64 mm) to large boulders (>256 mm), was impenetrable because of the adhesive nature of the iron floc.

There were many ground water seeps throughout the drainage, flowing into the Mike Horse Creek. These seeps were characterized by extremely thick mats of filamentous algae but no ferric hydroxide precipitate. Although no macroscopic plants were growing at station 2, _Pohlia annotina var. decipiens_, a rare terrestrial moss, was found in mats on the iron precipitate within the roofless, abandoned Mike Horse mine buildings. A species of _Pholia_ was found by Antonovics _et al_. (1971) growing on contaminated soils around mining operations.

Rocks, debris, and dead wood bordered the channel with no terrestrial streambank vegetation. Though the station was unprotected by bank vegetation, the water temperature was lower here than site 1. This was probably due to the cold mine effluent. The water was an orange color due to suspended iron hydroxide.

Site III-Lower Mike Horse Creek

Station 3 was located 0.6 km below site 2 and 13 m above the convergence with Beartrap Creek. It drained a 0.6 km^2 area. The stream bed was, in part, an old road, flowing in either one or two channels depending on the amount of discharge. The lower reaches of the station were severely altered due to the tailings pond dam breakage in 1975 and remains unstable. Ferric hydroxide precipitate was extensive at this site although somewhat diluted due to an increase in flow from surfacing ground water. Ferric hydroxide was precipitated at a rate of approximately 5 mm per month during the period of this study. The substrate, composed of gravel (8-16 mm) to boulder (256 mm), was coated with precipitate.

The channel here was wider (1-4 m) but more shallow than at site 2 (2-8 cm). The current was generally swift, causing a homogeneous habitat with no pools or well defined riffle areas. Discharge varied seasonally, 16.9 cfs (0.48 cms) during runoff to 5.7 cfs (0.16 cms) in August.

The stream's southeast margin was void of terrestrial plants and consisted of fragmented rock. The northwest bank was an eroded hillside with dead and dying lodgepole pine and Douglas fir hanging above the stream.

No aquatic or terrestrial animals were observed utilizing the waters of this station.

Site IV-Upper Beartrap Creek

Station 4 was located in a 457 m section of Beartrap Creek between the tailings pond and its confluence with the Mike Horse Creek. The drainage area of site 4 was 2.25 km^2. It was fed by surfacing ground water from below the dam and its west bank. Its channel was divided by a long narrow island running for approximately 100 m and was relatively straight and uniform. There was no ferric hydroxide precipitate at this station. There were no clearly defined riffle or backwater areas, with the stream having a fairly swift laminar flow. The substrate consisted of mostly pebble (4-16 mm) and gravel (16-64 mm) with a few cobble (64-256 mm) sized rocks. Channelization occurred during the dam breakage and subsequent rebuilding.

Beartrap Creek here was small, 1-2 m wide with depths ranging from 1-10 cm. The discharge was greater than the Mike Horse Creek, fluctuating between 27.4 cfs (0.78 cms) in June to 18.7 cfs (0.53 cms) in August. The water temperature was lower at station 4 than the Mike Horse Creek's temperatures because of the surfacing of the cooler water below the dam.

The banks were completely bare, consisting of fragmented rock and dead wood. Aquatic and terrestrial vegetation was abundant in the stream bed. Water-cress (*Rorippa nasturtium-aquiticum*) and *Potamogeton sp.* were found throughout the study period. Yellow monkey flower (*Mimulus sp.*) was abundant during July and *Bryum sp.*, a terrestrial moss, was also found growing on the exposed substrate of the stream. Approximately 60% of the substrate was covered with a dense growth of filamentous algae.

In a Montana Department of Fish and Game electroshocking fish survey done in 1972, 36 Cutthroat trout averaging 16.6 cm were found (Spence, 1975). No fish were observed during this study period, possibly because of the dam breakage in 1975. Deer tracks were observed along the banks of this station throughout the study.

Site V-Beartrap Creek

Site 5 was located on Beartrap Creek, 150 m below the convergence with Mike Horse Creek and drained a 2.86 km^2 area. The creek was wider here (2-3 m) with depths of 8 to 22.5 cm in the pools. The channel is characterized by considerable amounts of branches and snags forming small log jams causing pools to be established. Ferric hydroxide precipitate was present with clumps of filamentous algae being suspended within the floc. There was a diverse habitat consisting of extensive riffles and shallow pools but the substrate was cemented with precipitate. It consisted of gravel (16 mm) to boulder (256 mm) sized rocks.

Discharge rates ranged from 46.8 cfs (1.38 cms) in June to 22.5 cfs (0.64 cms) in August. The discharges from upper Beartrap and Mike Horse Creeks remained distinct for 100 m before thorough mixing occurred.

The east bank along station 5 was bare of vegetation and consisted of fragmented rock and debris. The west bank was a steep slope covered with vegetation similar to station 1.

The Montana Fish and Game Department found no fish at this station during their electroshocking survey (Spence, 1975). There were deer tracks in the area throughout the study.

Site VI-Upper Anaconda Creek

Anaconda Creek was used as a control stream during this study and site 6 was the upstream station. Its drainage area was 3.3 km^2. This site possessed a variety of habitats, characterized by an extensive riffle area with a moderate flow, small pools along the margin of the stream under overhanging banks, and Hygrohyphum diltatum, an aquatic moss, forming clumps within the streambed. The stream width varied from 1-3 m but was fairly shallow (4-15 cm). There was considerable fluctuation in the discharge rate which ranged from 25.2 cfs (0.71 cms) in June to 7.0 cfs (0.20 cms) in August.

Anaconda Creek above site 6 remained flowing throughout the study period. Between site 6 and 7 the flow became intermittent by the end of July and isolated, deep pools were formed. The substrate was stable, varying in size from very coarse sand (1-2 mm) and gravel (10 mm) to large cobble (64-256 mm). There was no ferric hydroxide precipitate at this station or logging occurring above the station.

Both banks were lined with mountain alder (Alnus incapa). At a few points, the shrubbery formed a cover which extended over the station. A steep, densely forested slope bordered the east bank with the west bank bordered by a small meadow filled with grasses and annual herbs. There were a few old structures still standing in the area built during the mining activity.

The Montana Department of Fish and Game fish survey in 1972 found 37 Cutthroat trout and two Brook trout with an average length of 11.5 cm in Anaconda Creek (Spence, 1975). During this study, trout were observed but never captured for positive identification.

Two Mule deer were observed drinking near site 6 and a variety of passerines were noticed using the stream. A Spotted Sandpiper with an immature were also seen in the stream.

Site VII-Middle Anaconda Creek

Site 7 was located 500 m below site 6 and drained a 4.0 km^2 area. This station was established to determine a chemical or biological effect caused by seepage through the alluvium between Anaconda and Beartrap Creeks. At this point, the streams were located 300 m apart.

Site 7 consisted of similar habitat to site 6 with extensive riffles, fewer pools, and only the west bank undercut. The substrate consisted of very coarse sand (1-2 mm) and gravel (4-16 mm) with some cobble (64-256 mm). There was some habitat degradation due to an abandoned road bordering the east bank. Only the west bank was lined with vegetation, consisting of mountain alder, lodgepole pine, and Douglas fir. For this reason, water temperatures were higher here than site 6.

The width and depth were similar to site 6, being 1-3 mm and 3.5 to 17 cm, respectively. Discharge varied from 24.9 cfs (0.68 cms) in June to 4.2 cfs (0.19 cms) in August. By the end of July, waters received at site 7 originated from the alluvium seeps 50 m above this station. Riffle areas still existed though pools were extremely shallow.

Aquatic and terrestrial life were similar to site 6.

Site IX-Upper Blackfoot River

Site 9 was located 500 m below the convergence of Beartrap and Anaconda Creeks to allow for thorough mixing of the two stream's waters. Immediately below the convergence, the river was extremely braided. The station was situated above a sharp bend in the river where an abandoned road crossed the bed. It drained a 7.08 km^2 area.

The substrate consisted of gravel (8-16 mm) to large boulder (>256 mm) with turbulent riffles and deep pools combining to form a diverse habitat. The ferric hydroxide precipitate was significantly reduced at this station but still encrusted the substrate. Filamentous algae, intertwined with the iron floc, was highly visible throughout the study.

The channel was 2 to 5 m wide and 7 to 57.6 cm deep. The discharge rate ranged from 124 cfs (3.53 cms) in June to 48.9 cfs (1.38 cms) in August.

Because of the erosion of the west bank, there were several dying trees overhanging the channel. The west bank was steep and heavily forested. The east bank was unstable, consisting of gangue piles and the abandoned road.

In July, there was a 3 m clump of *Equisetum fluvatile* on the east bank, 300 m below the convergence. An unidentified frog(s) was (were) observed several times within this stand. No fish were reported by the Montana Department of Fish and Game during their electroshocking survey in 1972 (Spence, 1975). Deer tracks were frequently seen along the banks and a Spotted Sandpiper and immature were observed within the river.

CHAPTER IV

RESULTS AND DISCUSSION

Chemical and Physical Characteristics

Acid Mine Drainage

Acid mine drainage occurs when metal sulfides are oxidized by either atmospheric or dissolved oxygen in percolating ground water. The chemical equation for this reaction is:

(1) Pyrite exposed to air and water:

$$2FeS_2 + 7O_2 + 2H_2O \longrightarrow 2H_2SO_4 + 2FeSO_4$$

(iron sulphide) (sulfuric acid) + (ferrous sulfate)

(2) Oxidation of ferrous sulfate in solution by dissolved oxygen to ferric sulfate:

$$4FeSO_4 + O_2 + 2H_2SO_4 \longrightarrow 2Fe_2(SO_4)_3 + 2H_2O$$

(ferrous sulfate) (ferric sulfate)

(3) Hydrolysis of ferric sulfate with water produces colloidal ferric hydroxide and sulfuric acid:

$$Fe_2(SO_4)_3 + 6H_2O \longrightarrow 2Fe(OH)_3 + H_2SO_4$$

(ferric sulfate) (ferric hydroxide) + (sulfuric acid)

(Ahmad, 1971)

This reaction causes a decrease in pH, an increase in dissolved metals, and an iron precipitate to form. Nichlos and Bulow (1973) characterized acid mine drainage waters as having:

pH............................	<6.0
Alkalinity....................	<20.0 mg/l as $CaCO_3$
Total Iron....................	>0.5 mg/l

Sulfate.............................>75.0 mg/l
Total Hardness.....................>150.0 mg/l

High total hardness, however, benefits acid mine streams with respect to the aquatic inhabitants. Hardness has been found to be antagonistic toward zinc, copper, cadmium, and lead, therefore causing the synergistic effect between copper, cadmium, and zinc to disappear in hard waters (Wentz, 1974).

Stations 1,2,3,5,9, and the seep possess many of the characteristics of acid mine drainage as defiened by Nichlos and Bulow (1973) (Table 1). The pH of these stations was not below 6.0, however. Alkalinity was greater than 20 mg/l, caused by the majority of the carbon to be in the carbonate and bicarbonate form associated with the high pH found at the polluted stations.

Some investigators (Cairns *et al.*, 1971; Brezina *et al.*, 1970; and Parsons, 1968) consider sulfate as the best water parameter in identifying acid mine drainage because of its intimate role in pyrite oxidation, low concentration in natural water (<20 mg/l), and its relative inertness, therefore remaining detectable. Specific conductance has also been used as a reliable indicator of acid mine pollution since it correlates with both the geochemical character (ionic solute) of the water and the chemical weathering (dissolved solids) consequent to the acid mine drainage (Pickering and Musser, 1970).

Results

Physiochemical data for the Mike Horse Mine is presented in Appendix A. Results will be organized and discussed by

Table 1. Comparison of acid mine drainage parameters.

Water parameter	6	7	4	1	2	seep	3	5	9	Acid Mine Character* (mg/l)
Specific cond. (uhos/cm)										
5/23/77	145	155	420	180	525	230	420	360	215	
6/21/77	120	120	470	150	680	190	470	290	220	
7/29/77	160	165	320	200	830	370	780	485	330	
Sulfate										
5/23/77	1.4	2.0	1.1	139	914	140	420	135	14	
6/21/77	4.0	1.7	5.0	49	395	39	200	140	31	>75
Total Hardness										
5/23/77	95	90	120	120	550	160	440	320	230	
6/21/77	65	70	75	95	420	140	320	290	210	
7/29/77	110	115	85	160	610	210	560	410	320	>150
Total Iron										
6/06/77	<.02	<.02	.05	NS	18	NS	9.7	2.2	0.71	
7/29/77	.03	.02	.10	NS	7.0	0.6	5.7	3.0	0.69	>0.5
Alkalinity										
5/23/77	23.7	29.6	56.4	42.5	58.1	45.2	30.8	30.7	38.4	
6/21/77	41.0	46.1	60.0	43.6	62.4	60.3	40.9	30.7	28.5	<20
pH										
5/23/77	7.6	7.9	7.2	7.3	6.8	7.5	7.1	7.2	7.5	
6/21/77	7.6	7.8	7.3	7.3	6.9	7.3	7.3	7.4	7.5	<6.0
7/29/77	7.6	7.9	7.7	7.6	7.2	6.7	7.7	7.4	7.8	

*Nichlos and Bulow, 1973

stations polluted with acid mine drainage, 2, 3, 5, and 9, and those classified by acid mine drainage as unpolluted, stations 4, 6, and 7. Station 1 and a seep in the Mike Horse drainage have characteristics of both acid mine drainage and an unpolluted stream. These stations will be classified as polluted stations due to their similarity in biological data with the polluted sites.

Unpolluted Stations

Upper Beartrap Creek (4), Upper Anaconda Creek (6), and Lower Anaconda Creek (7).

Discharge

Discharge fluctuated seasonally at all three of the unpolluted stations (Figure 4a). The lowest and highest observed discharge for stations 6 and 7 occurred on the same sampling data, July 29 and June 21, respectively. Peak discharge at stations 6 and 7 were 25.2 cfs (cubic feet per second) and 24.2 cfs, respectively. All readings were higher at station 6, the upstream site, which indicated a seepage into the alluvium between the two stations. By the end of July, discharge had decreased to 7.0 cfs at station 6 and 4.2 cfs at station 7. The seepage into the alluvium became most apparent as station 7 became a standing pool in September. Station 4 exhibited a different runoff pattern due to the influence of the dam above this station. While all the other stations were recording their lowest discharge in July, the flow at station 4 did not decrease significantly (Figure 4a). The discharge at this station rose from

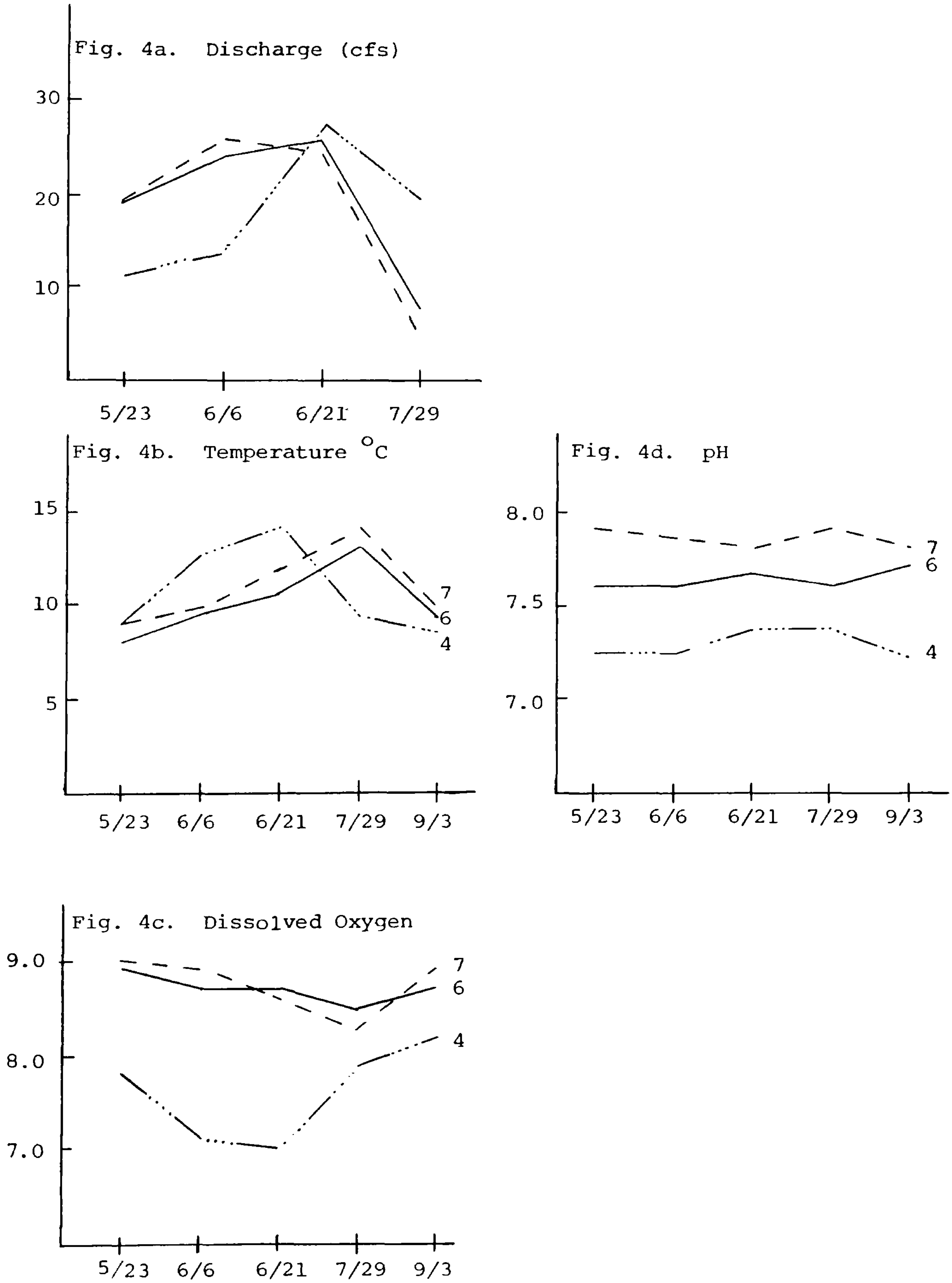


Figure 4a-d. Comparison of discharge, temperature, dissolved oxygen, and pH at the unpolluted stations-4,6, and 7.

10.97 cfs on 23 May to a peak of 27.5 cfs on 21 June. By 29 July, recorded discharge was calculated to be 18.7 cfs.

Temperature

Water temperature varied seasonally at each station depending upon the drainage pattern of the stream and its bank characteristics. The temperature ranges for stations 4, 6, and 7 were identical during the study period. Their minimum and maximum readings occurred on different dates (Figure 4b). The maximum recorded temperature of 14°C at station 4 was considerably earlier than those of stations 6 and 7. Their highest recorded temperature occurred on 29 July. A considerable decrease in discharge appears to be the cause of these late maximum readings at stations 6 and 7. Minimum recorded temperatures of 8° and 9°C occurred in May at stations 6 and 7, respectively. The lowest temperature at station 4 of 8.5°C was recorded in September.

Dissolved Oxygen

At all three of the unpolluted stations, dissolved oxygen (DO) and temperature exhibited an inverse correlation. The lowest DO concentrations were recorded when water temperatures were highest. The DO concentrations of stations 6 and 7 ranged from 8.3-9.0 ppm (Figure 4c). Minimum and maximum readings were found in August and May, respectively. Station 4 had DO concentrations in the range of 7.0-8.2 ppm. The maximum DO of this station was the minimum of stations 6 and 7. Minimum readings of 7.0 ppm occurred in June and a maximum reading of 8.2 ppm occurred in September at station 4.

Total Alkalinity and Hardness

Total alkalinity and hardness varied inversely during the sampling period at all three unpolluted stations. There was a longitudinal increase in alkalinity from station 6 to 7. Alkalinity and hardness concentrations were highest at station 4. The ranges at station 4 were 56.4 to 60.3 mg/l as $CaCO_3$ for alkalinity and 75 to 120 mg/l for total hardness (Figure 5a and b). The ranges of total alkalinity and hardness at station 6 were from 23.7 to 41.0 mg/l and from 80 to 115 mg/l, respectively. At station 7, alkalinity and hardness concentrations ranged from 23.7 to 41.0 mg/l as $CaCO_3$ and from 65 to 110 mg/l, respectively. Total alkalinity increased while hardness decreased as the stream discharge rose at all three stations.

Calcium and Magnesium

The concentrations of calcium and magnesium decreased with an increase in discharge at stations 6 and 7. A ratio of 2:1 (Ca:Mg) was maintained during both sampling periods between these two constituents. Concentrations at these two stations ranged from 20 to 30 mg/l calcium and from 10 to 18 mg/l for magnesium (Figure 5c and d). At station 4, calcium and magnesium increased as discharge increased. Their respective ranges were 40 to 46 mg/l and 28 to 36 mg/l (Figure 5c and d).

Sulfate

Sulfate concentrations at stations 4, 6, and 7 were below 4.0 mg/l throughout the sampling period (Figure 6a). There was a

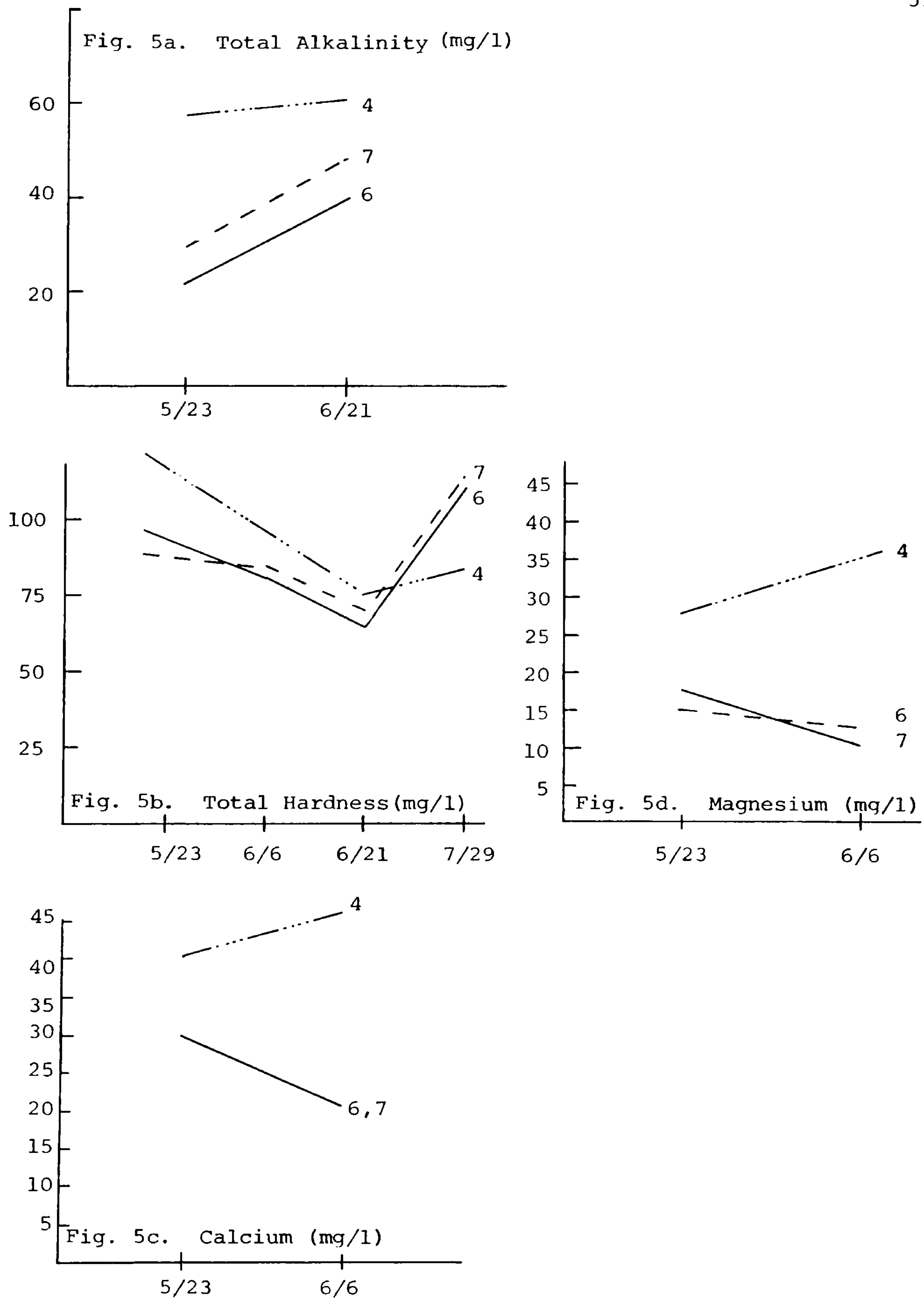


Figure 5a-d. Comparison of total alkalinity, total hardness, calcium, and magnesium at the unpolluted stations-4,6, and 7.

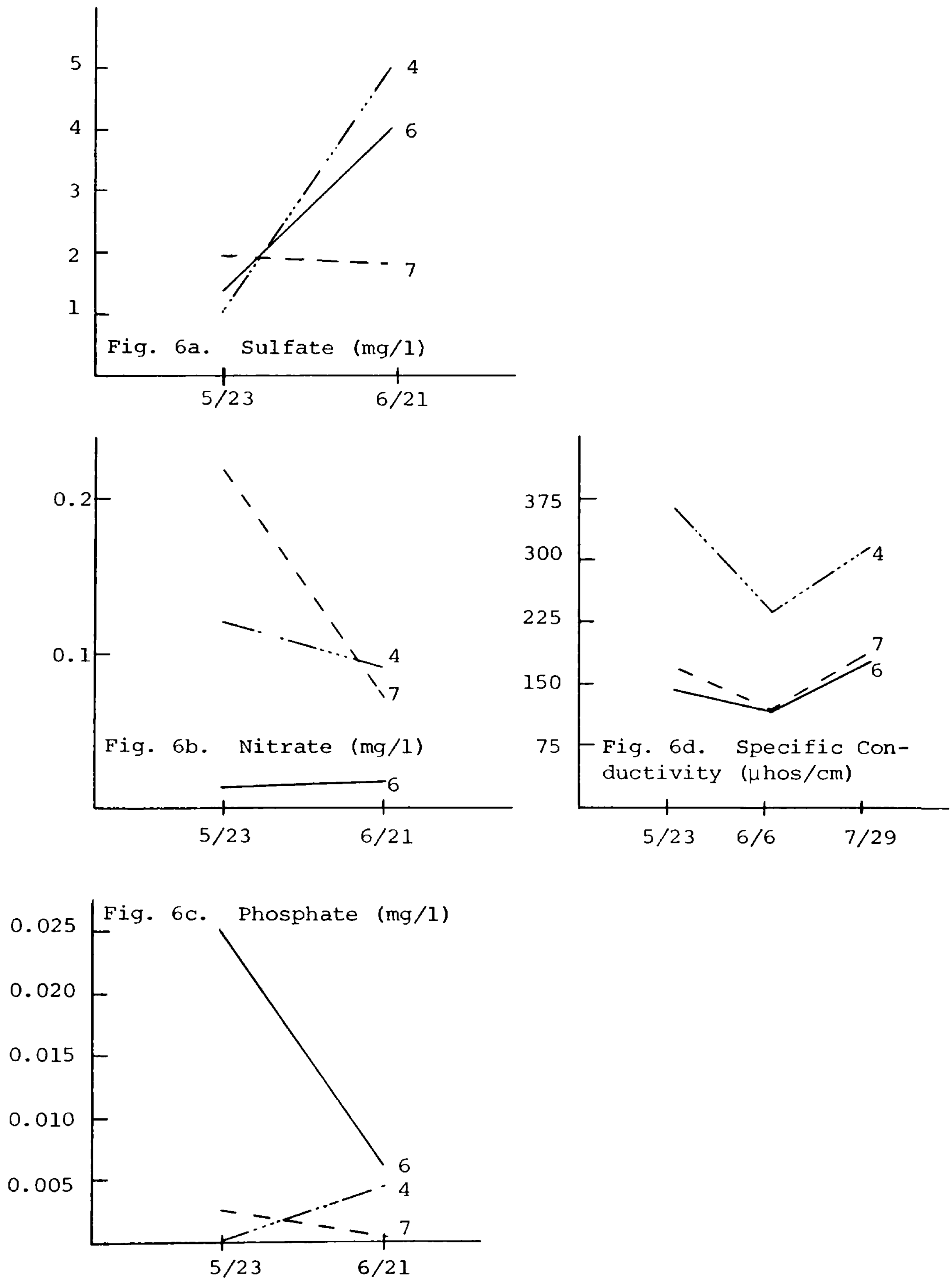


Figure 6a-d. Comparison of sulfate, nitrate, phosphate, and specific conductivity at the unpolluted stations-4,6, and 7.

decrease in sulfate concentrations with an increase in flow at station 7. As discharge increased at stations 4 and 6 there was an increase in sulfate concentrations.

Nitrate and Phosphate

Nitrate and phosphate concentrations were low throughout the study period at stations 6 and 7. This is typical of small mountain streams where these nutrients are readily assimilated by the algal biomass. At station 6, nitrate concentrations increased with an increase in discharge from 0.0065 in May to 0.008 mg/l in June (Figure 6b). Phosphate decreased with an increased discharge at station 6 (Figure 6c). Nitrate concentrations were higher at station 7 than station 6, with recorded readings of 0.22 mg/l in May and 0.07 mg/l in June (Figure 6b). Phosphate decreased with runoff from 0.0025 mg/l in May to 0.002 mg/l in June at station 7. At station 4, nitrate concentrations ranged from 0.09 mg/l to 0.12 mg/l (Figure 6b and c). These higher concentrations are caused by the dam above this station. Hilsenhoff (1971) and Spence and Hynes (1971) found an increase in nitrate and phosphate below hypolimnion impoundments. Phosphate concentrations were inversely correlated to nitrate. Phosphate increased during runoff from 0.0008 mg/l in May to 0.0045 mg/l in June.

Specific Conductivity

At the unpolluted sites, specific conductivity was positively correlated with total hardness throughout the study. Specific conductivity was inversely related to discharge rate and alkalinity.

Readings were significantly higher at station 4 compared to stations 6 and 7. Specific conductivity ranged from a low of 230 μhos/cm in June to a high of 360 μhos/cm in May (Figure 6d). The specific conductivity varied little between stations 6 and 7 (Figure 6d). Lowest recordings were in June of 120 μhos/cm and highest readings were found in July of 160 to 165 μhos/cm.

Heavy Metals

Analyses for dissolved and total recoverable arsenic, cadmium, copper, iron, lead, and zinc were done twice during the study period at stations 4, 6, and 7. Water samples were collected during runoff (June) and again during the lowest recorded flow (July). The majority of the concentrations were below a detectable level during runoff at stations 6 and 7 (Table 2). Total recoverable (TR) arsenic was the only metal found above the detectable level during June of 0.001 mg/l. With a three-fold decrease in discharge at station 6 by the end of July, the TR arsenic doubled to 0.002 mg/l and 50% of this concentration was in the soluble form (Table 3). Iron increased to 0.03 mg/l in July at station 6 with 100% being in the dissolved form. Dissolved zinc also increased to 0.01 mg/l during the second sampling period. None of these concentrations, however, were above the maximum concentrations for fish and other aquatic organisms suggested by Wentz (1974) (Table 2). The source of arsenic, iron, and zinc at station 6 appears to remain constant as discharge decreases. Therefore, there was an increase in heavy metal concentrations at this station during lower flow.

Table 2. Concentrations of Heavy Metals at the unpolluted stations, 4, 6, and 7 compared with suggested limits for aquatic life and drinking water in mg/l.

Metal		6	7	4	max. suggested conc. for fish & aquatic life*	USPHS drinking water stand.****
6/06/77						
Arsenic-dis**		<0.001	0.001	<0.001		
	TR***	0.001	<0.001	0.001	--	0.05
Cadmium-dis		<0.001	<0.001	<0.001		
	TR	<0.001	<0.001	<0.001	0.01	0.01 CR*****
Copper-	dis	<0.01	<0.01	<0.01		
	TR	<0.01	<0.01	<0.01	0.01-0.02	1.0 SL****
Iron-	dis	<0.02	<0.02	<0.02		
	TR	<0.02	<0.02	0.05	0.3	0.3 SL
Lead	both forms below detectable level				0.05-0.1	0.05 CR
Zinc-	dis	<0.01	0.08	0.13		
	TR	<0.01	<0.01	0.13	0.03-0.07	5.0 SL
7/29/77						
Arsenic-dis		0.001	<0.001	<0.001		
	TR	0.002	0.001	0.001		
Cadmium-dis		<0.001	<0.001	<0.001		
	TR	<0.001	<0.001	<0.001		
Copper-	dis	<0.01	<0.01	<0.01		
	TR	<0.01	<0.01	<0.01		
Iron-	dis	0.03	0.02	0.03		
	TR	0.03	0.02	0.10		
Lead	both forms below detectable levels					
Zinc-	dis	0.03	0.02	0.21		
	TR	0.01	0.02	0.14		

*Wentz, 1974
**dissolved
***Total recoverable
****Suggested limit
*****Cause for rejection limit

Table 3. Percent dissolved metals for the unpolluted stations - 4, 6, and 7.

Metal		6	7	4
Arsenic	6/06/77	<dl*	<dl	<dl
	7/29/77	50%	<dl	<dl
Cadmium	6/06/77	<dl	<dl	<dl
	7/29/77	<dl	<dl	<dl
Copper	6/06/77	<dl	dl	<dl
	7/29/77	<dl	<dl	<dl
Iron	6/06/77	<dl	<dl	<dl
	7/29/77	100%	100%	30%
Lead		below a detectable level (0.05 mg/l) during both sampling periods		
Zinc	6/06/77	<dl	100%	100%
	7/29/77	100%	100%	100%

*detectable level

A five-fold decrease in discharge at station 6 by the end of July caused dissolved iron to become detectable at 0.02 mg/l (Table 2). TR arsenic remained at 0.002 mg/l during both sampling periods. Dissolved zinc increased from below the detectable level in June to 0.02 mg/l by the end of July. A decrease in discharge caused dissolved zinc and iron to increase at station 7 though concentrations did not increase at lower discharge rates.

At station 4, an increase in discharge caused an increase in the concentrations of iron and zinc (Table 2). Iron increased from 0.05 mg/l in June to 0.10 mg/l in July. Only 30% of the iron was in a soluble form during July (Table 3). Dissolved zinc concentrations increased from 0.13 mg/l to 0.21 mg/l during this same time period. These concentrations exceeded the maximum dissolved concentration for fish and other aquatic life suggested by Wentz (1974) for zinc (Table 2).

Polluted Stations

Upper Mike Horse Creek (1), Middle Mike Horse Creek (2), Seep in Mike Horse Drainage, Lower Mike Horse Creek (3), Lower Mike Horse Creek (5), and Upper Blackfoot River (9).

Station 1 and the seep were not directly affected by the waters from the Mike Horse Mine but were chemically altered due to past mining activities. Both sites were recently surfaced ground water and possessed many of the characteristics of water polluted by acid mine drainage. Neither station was coated with the ferric hydroxide precipitate, however.

Physiochemical data for the Mike Horse Mine is presented in Appendix A. This information will not be discussed as a station in itself. It was the only detectable source of the pollution and will be discussed with respect to the other sites.

Discharge

The peak observed discharge occurred in June for all six polluted stations. Discharge increased longitudinally from station 1 to station 9 (Figure 7a and b). By the end of July, all stations recorded significantly lower discharge readings. The observed peak discharge at station 1 of 8.58 cfs was recorded on 21 June with rising levels before this data (Figure 7a). By 29 July, discharge had decreased to 1.27 cfs at this station. Water from the Mike Horse Mine and station 1 flowed into station 2. There was an interesting pattern of discharge at this station throughout the study period. Discharge of station 2 was consistently lower than the combined total of its sources. It appears that a considerable amount of water goes into the alluvium before reaching station 2. Maximum observed discharge of 11.5 cfs was recorded on 6 June with a steady decrease to 3.0 cfs by 20 July (Figure 7a). The combined total discharge from station 1 and the mine were 18.5 and 3.5 cfs for these two dates.

Discharge from the seep increased until 21 June when it peaked at 6.28 cfs (Figure 7a). It then decreased to 1.9 cfs by 20 July. Between stations 2 and 3, considerable amounts of water was added from seeps such as the one mentioned above. Station 3 reached its

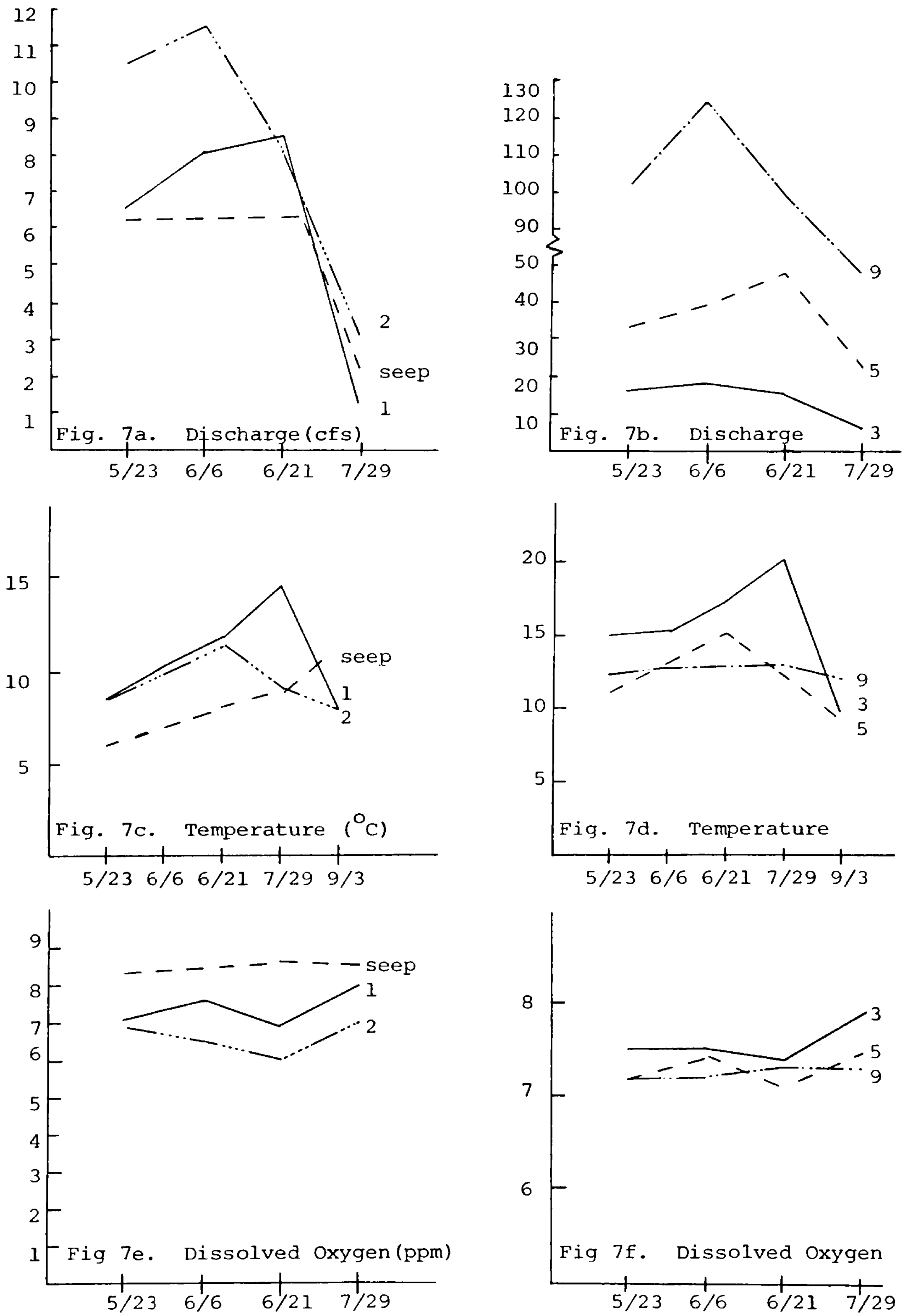


Figure 7a-f. Comparison of discharge, temperature, and dissolved oxygen at the polluted stations-1,2,3,5,9,and the seep.

highest recorded discharge on 6 June of 16.9 cfs. Discharge dropped to 5.7 cfs by 29 July (Figure 7b). Station 5, a combination of discharges from stations 3 and 4, steadily rose to a peak flow of 48.6 cfs on 21 June (Figure 7b). Station 4 also exhibited a maximum discharge of 27.5 cfs on this same date. The peak discharge of station 3 was recorded two weeks prior. Discharge from stations 3 and 4 varied throughout the study period. In May and early June, higher quantities of water were contributed from station 3 to station 5. Later in the study period, as a consequence of the impoundment, the majority of the water received at station 5 was contributed by station 4. During runoff, discharge readings at station 5 were higher than the combined totals of stations 3 and 4. Added quantities of ground water appear to be surfacing above station 5. By the end of July, however, the discharge of 22.5 cfs was lower than the combined totals from stations 3 and 4. Non-surfacing ground water may explain this result.

Station 9 obtained considerable quantities of water from intermittent streams and ground water as well as from stations 5 and 7. By the end of July, no surface water from Anaconda Creek was reaching station 9. The peak recorded discharge of station 9 was 124.56 cfs on 6 June. The minimum observed discharge at this station of 48.88 cfs was recorded on 29 July (Figure 7b).

Temperature

Water temperature varied between 6° and 20°C throughout the study period at the six polluted stations. The maximum temperature of 20°C was found at station 3 on 29 July (Figure 7d). The minimum temperature of 6°C was found at the seep on 23 May. The temperature of the water at station 1 increased to a maximum of 14.5°C on 29 July. A minimum of 8.0°C was found on 3 September (Figure 7c). Because of the colder water from the mine, the temperatures of station 2 were lower than station 1 (Figure 7c). A maximum of 11.5°C was recorded on 21 June and a minimum of 8.0°C was found on 3 September. Station 3 had the highest overall temperatures due to its open banks (Figure 7d). It increased to a maximum of 20°C on 29 July and decreased to a low of 10°C on 3 September. The maximum temperature of 15°C at station 5 was recorded when stations 3 and 4 had also reached their peaks (Figure 7d). A minimum of 9°C was found on 3 September. Station 9 maintained a fairly constant temperature of 12 to 13°C throughout the study period (Figure 7d).

Dissolved Oxygen

With the exception of station 1, dissolved oxygen (DO) did not exhibit the usual inverse correlation to temperature at the polluted stations. Station 1 exhibited the lowest DO of 6.9 ppm on 29 July and its highest oxygen concentrations of 8.0 ppm were found on 3 September (Figure 7e). Dissolved oxygen levels at the seep were the highest of all the polluted stations. Throughout the study period a constant level of 8.3 to 8.6 ppm was maintained (Figure 7e).

The remaining four stations had no particular dissolved oxygen pattern though the concentrations were all lower than 7.9 (Figure 7e and f). The dissolved oxygen levels rose with increasing distance from the mine waters. The mine waters ranged between 54-69% oxygen saturated through the study period. This was probably because of the oxidation of ferrous iron by dissolved oxygen.

pH

The pH of each site remained relatively constant throughout the study period (Figure 8a and b). At station 1, pH was stable at 7.3 through May and June with a slight increase to 7.6 in August. It declined to 7.3 by 3 September (Figure 8a). As a consequence of the lower pH of the mine waters, this parameter was also reduced at station 2. The pH increased from 6.8 in May to 7.2 by the end of July and decreased again to 6.7 by September (Figure 8a). The pH of the seep acted inversely to station 2. Highest readings of 7.5 were found in May and dropped to 6.7 and 6.8 in July and September, respectively (Figure 8a). The pH at station 3 fluctuated similarly to that of station 2 (Figure 8b). It increased from 7.1 in May to 7.7 by 29 July and decreased to 7.2 by September. The pH at station 5 remained fairly constant throughout the study period. It exhibited a pattern similar to station 4. The pH at station 5 rose from 7.2 in May to a steady reading of 7.4 from June to August (Figure 8b). It decreased to 7.3 by 3 September. There was an overall longitudinal increase in pH at station 9 (Figure 8b). The pH was steady at 7.5 to 7.55 from May to July with an increase to 7.8 by the end of July. It decreased to 7.6 by September.

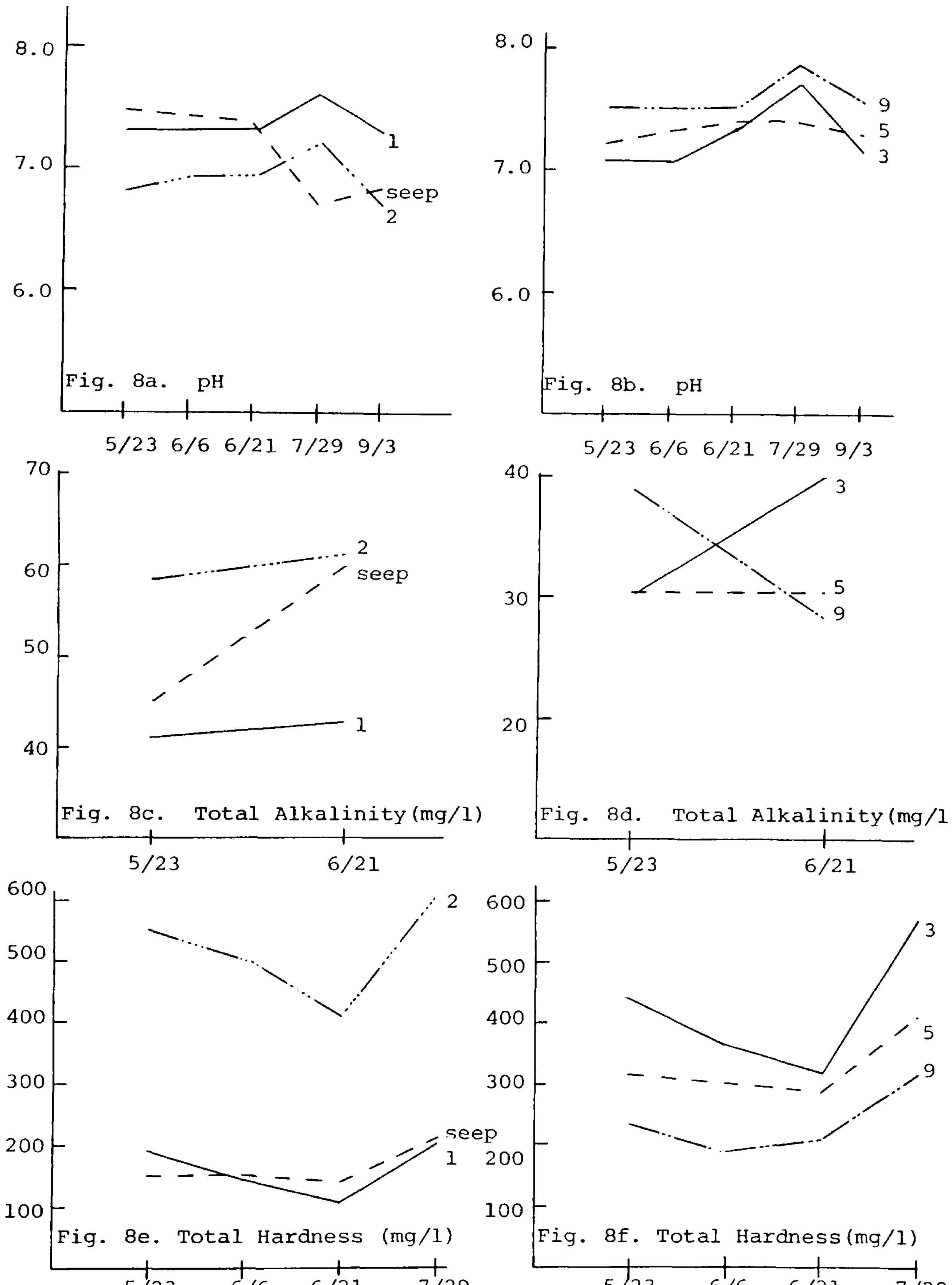


Figure 8a- f. Comparison of pH, total alkalinity, and total hardness at the polluted stations-1,2,3,5,9, and the seep.

Total Alkalinity and Hardness

Total alkalinity decreased with distance from the pollution source at the stations affected by mine drainage. It also increased with an increase in discharge at all six stations. Total alkalinity did not exhibit the characteristic concentrations found in streams polluted by acid mine drainage (Table 1). This was correlated with the pH of these stations being above 6.0. A pH lower than 4.5 destroys the buffering capacity of the stream causing the recorded alkalinity to be 0. This is caused by carbonate and bicarbonate, the two major contributors to the buffering capacity of alkalinity of a stream, not being present below a pH of 4.5. As the pH decreases, carbon dioxide becomes the major carbon source.

Total hardness reacted inversely to alkalinity. It increased with a decrease in discharge. During the majority of the sampling periods, all stations were characterized by total hardness concentrations typical of waters polluted by acid mine drainage (>150 mg/l).

At station 1, alkalinity demonstrated a slight increase from 42.5 mg/l in May to 43.6 mg/l in June (Figure 8c). Total hardness increased at this station from 75 to 140 mg/l with a decrease in discharge (Figure 8e). Alkalinity increased from 58.1 to 62.4 mg/l as $CaCO_3$ in May and June, respectively, at station 2. Total hardness ranged from 420 to 550 mg/l during runoff and increased to 610 mg/l by the end of July (Figure 8c and e). Alkalinity of the water from the seep also increased from 45.2 mg/l in May to 60.3 mg/l in June (Figure 8c). Total hardness ranged from 140 to 160 mg/l during runoff and increased to 210 mg/l by 20 July (Figure 8e). At station 3, alkalinity increased from 30.9 mg/l in May to 40.9 mg/l in June (Figure 8d). A range of 320 to 440 mg/l for total hardness was recorded during this same time period. On 29 July, hardness increased to 560 mg/l (Figure 8f). At station 5 alkalinity was constant at 30.7 mg/l as $CaCO_3$ during both sampling periods (Figure 8d). Hardness varied slightly from 290 mg/l to 320 mg/l during runoff (Figure 8f). A sharp increase to 410 mg/l was observed when discharge decreased. The alkalinity range at station 9 was 28.5 to 38.4 mg/l (Figure 8d). Total hardness fluctuated from 190 to 230 mg/l during May and June with an increase to 320 mg/l by the end of July.

Calcium and Magnesium

Calcium and magnesium exhibited no particular overall pattern during the study period. They were positively correlated with each other, however. These two parameters increased with a rise in discharge from 25 to 45 mg/l for calcium and 14 to 32 mg/l for magnesium at station 1. Calcium and magnesium also increased with an increase in discharge at the seep (Figure 9a and c). These two constituents decreased with an increase in discharge at station 2. Their ranges were 58 to 78 mg/l for calcium and 48 to 62 for magnesium (Figure 9a and c). At station 3, calcium and magnesium increased with a slight decrease in flow. Calcium fluctuated from 62 to 72 mg/l and magnesium ranged from 41 to 60 mg/l (Figure 9b and d). These two constituents varied inversely with stream discharge at station 5. They varied from 50 to 70 mg/l and 39 to 55 mg/l for

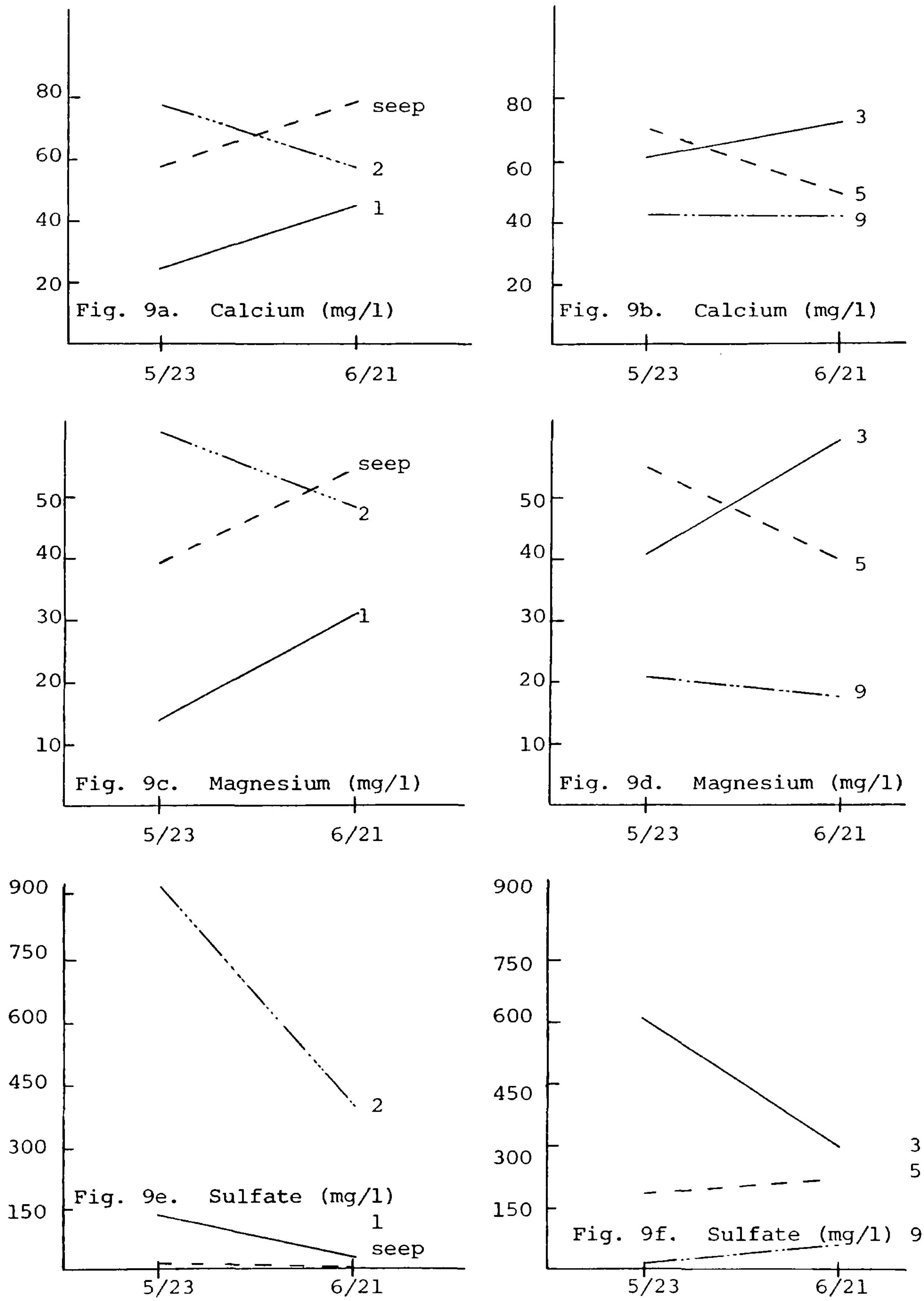


Figure 9a- f. Comparison of calcium, magnesium, and sulfate at the polluted stations-1,2,3,5,9, and the seep.

calcium and magnesium, respectively (Figure 9b and d). Calcium and magnesium varied only slightly at station 9 during May and June. There was no change in calcium and only a slight increase in magnesium from 17 to 21 mg/l (Figure 9b and d).

Sulfate

Sulfate levels greater than 75 mg/l are indicative of acid mine drainage. All stations, except the seep and station 9, exhibited concentrations above this value. Sulfate was highest at station 2 and decreased with increasing distance from the mine. In all cases, sulfate concentrations were inversely proportional to stream discharge. An increase in runoff caused a dilution of the sulfate concentrations.

At station 1, sulfate concentrations varied from 139 mg/l in May to 49 mg/l in June (Figure 9e). Because of the inflow of mine water, sulfate concentrations increased considerably at station 2. Concentrations of 9.4 mg/l were found in May and 395 mg/l were recorded in June (Figure 9e). Sulfate concentrations at the seep ranged from 14.0 mg/l in May to 5.0 mg/l in June (Figure 9e). At station 3, sulfate concentrations were lower than at station 2. These concentrations were 420 mg/l in May and 200 mg/l in June (Figure 9f). Sulfate was further diluted at station 5 by the discharge from station 4. The sulfate concentrations varied by only 5 mg/l between the two sampling periods. They were 135 mg/l in May and 140 mg/l in June (Figure 9f). There was a drastic reduction in sulfate at station 9. Concentrations of 14.0 mg/l were found in May and increased to 31.0 mg/l by June. This was the only station where sulfate concentrations varied directly correlated with an increase in discharge (Figure 9f).

Nitrate and Phosphate

Phosphate was low (0.008 mg/l) at all the polluted stations during the study period (Figure 10a and b). Nitrate concentrations were higher during May than June at all stations except station 9 (Figure 10c and d). Maximum readings were found at the seep (0.021 to 0.025 mg/l) with the lowest readings occurring in June at station 2 (0.006 mg/l).

Specific Conductivity

Specific conductivity at the polluted stations was two to seven times greater than the conductivity found at the unpolluted stations. High specific conductivity is characteristic of waters polluted by acid mine drainage due to high concentrations of inorganic ions. Specific conductivity varied indirectly with discharge at all stations. Dilution of the inorganic ions was apparent as distance from the mine increased.

Specific conductivity ranged from a low of 130 μhos/cm at station 1 (above the mine) to 830 μhos/cm at station 2 (below the mine). Ranges at station 1 were from 130 μhos/cm in June and increased to 200 μhos/cm by August (Figure 10e). The conductivity at station 2 was highest in August with 830 μhos/cm and lowest in early June with 450 μhos/cm (Figure 10e). The conductivity at the seep was higher during the entire sampling period than station 1. The more water percolates through the earth, the more material that will be in a

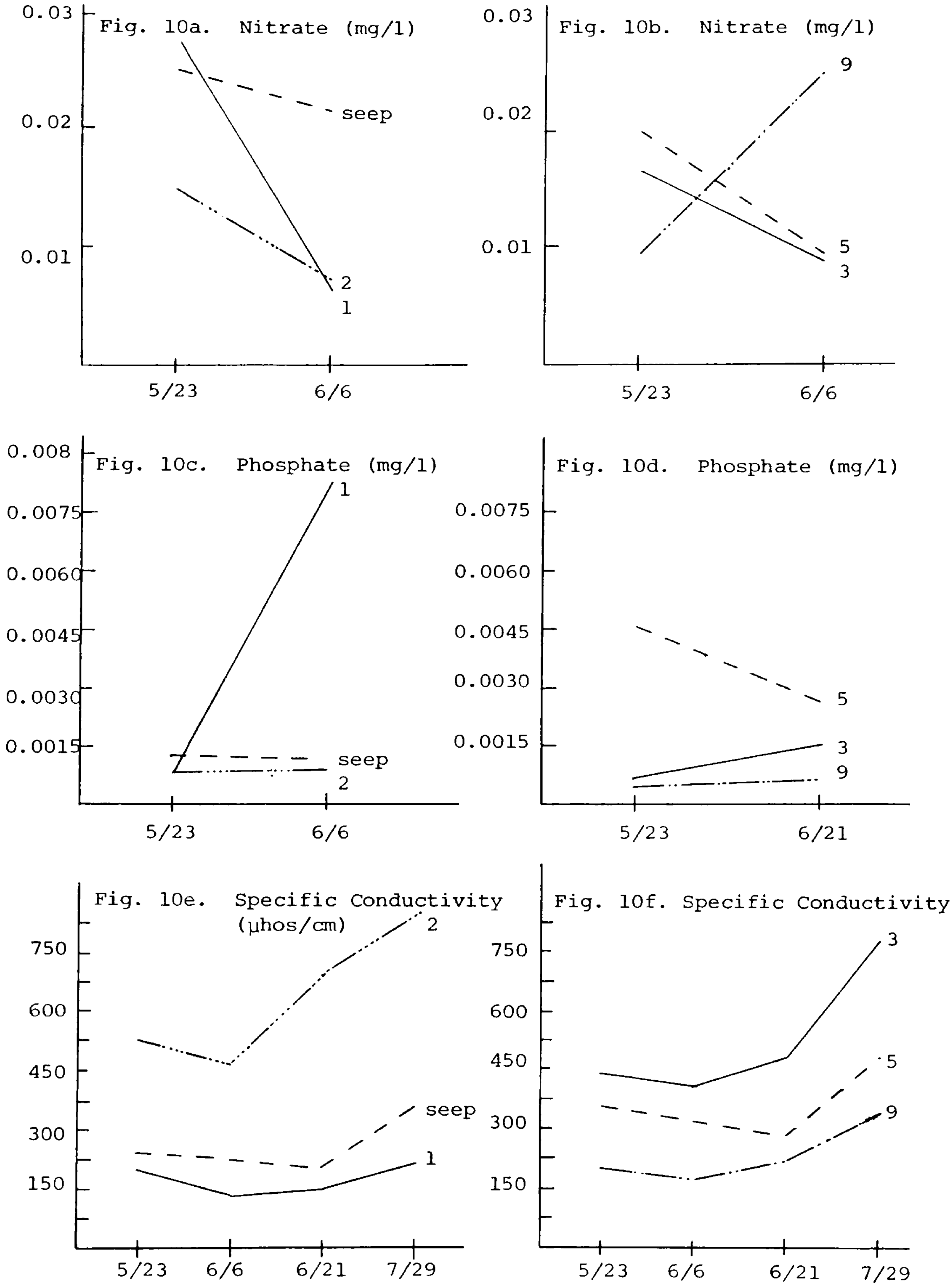


Figure 10a-f. Comparison of nitrate,phosphate, and specific conductivity at the polluted stations-1,2,3,5,9, and the seep.

dissolved form in the water. Specific conductivity ranged from 370 µhos/cm in July to 190 µhos/cm in June (Figure 10e). Specific conductivity remained high at station 3. Readings ranged from 310 µhos/cm in June to 780 µhos/cm by the end of July (Figure 10f). At station 5, conductivity readings were at a maximum on 29 July with 485 µhos/cm and diluted by increased runoff to 290 µhos/cm on 21 June (Figure 10f). This parameter at station 9 was lowest in June (190 µhos/cm) with a high of 330 µhos/cm on 29 July (Figure 10f).

Heavy Metals

Analyses for arsenic, cadmium, copper, iron, lead and zinc were made at the Mike Horse mine, the seep (on July 29), and stations 2, 3, 5, and 9. Dissolved and total recoverable (TR) forms were sampled two times during the study period. The mine exhibited the highest concentrations of all six metals, TR and dissolved, and was the only detectable source of heavy metals in the drainage (Appendix Table 5). There was a longitudinal dilution of the metals as distance from the mine mouth increased (Figure 11).

The majority of the total and dissolved concentrations of metals decreased with a decrease in discharge although there were a few exceptions. Total copper exhibited a pattern of increasing with a decrease in discharge at all stations. Total copper analyzed from the mine water, however, remained constant during both sampling periods. It appears that total copper may be added from another source other than the mine. Dissolved copper decreased with a

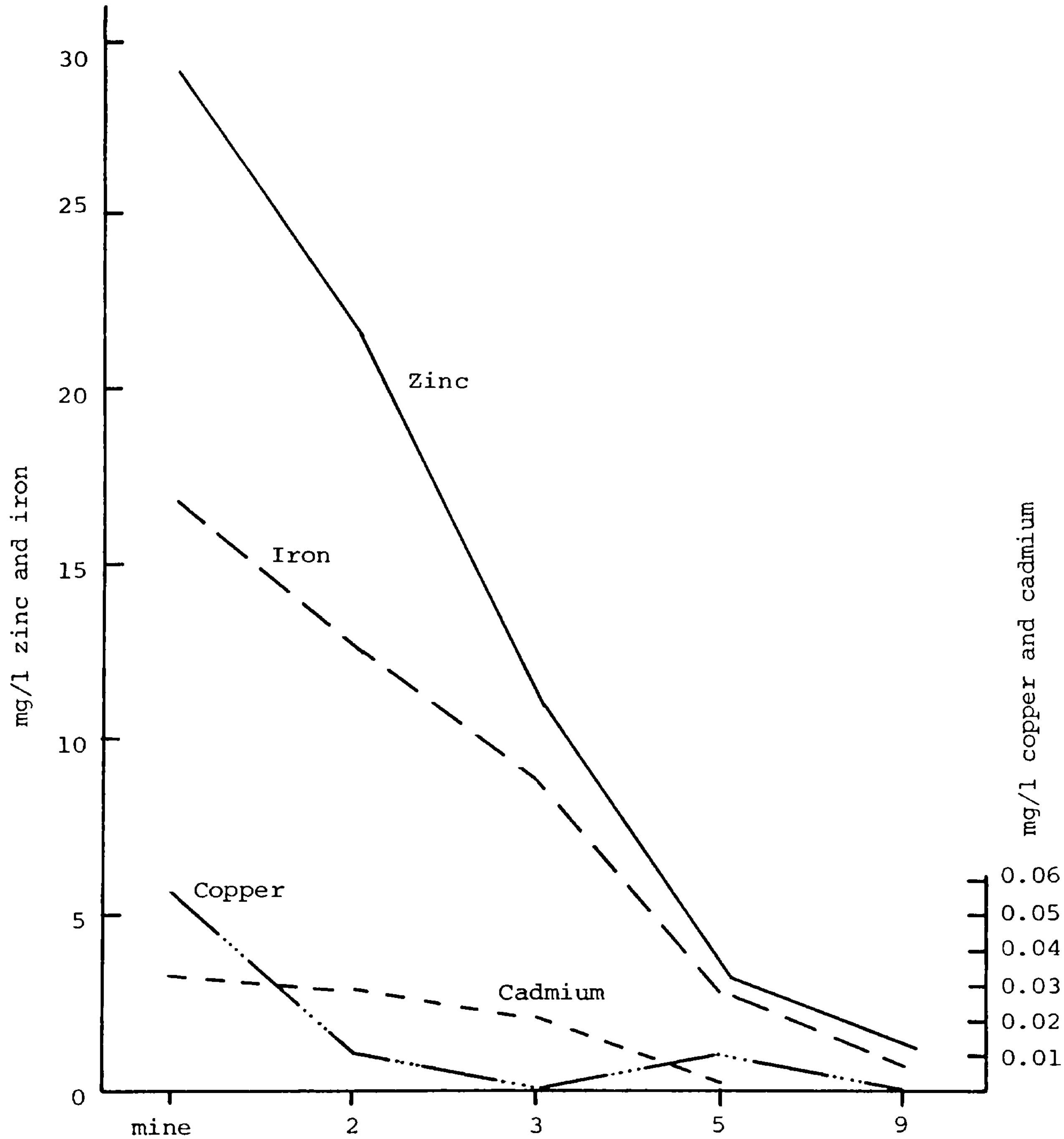


Figure 11. Behavior of dissolved zinc, copper and cadmium and total recoverable iron with increase distance from mine(mg/l). Note: Expanded scale for dissolved copper and cadmium concentrations.

decrease in discharge but this was a result of an increase in pH causing more of the copper to become insoluble (Figure 12).

Dissolved and total recoverable zinc was the metal in highest concentrations at all the polluted stations (Figure 13a-e). TR concentrations ranged from a high of 29.0 mg/l at station 2 to a low of 1.4 mg/l at station 9 (Figure 13e). Dissolved zinc varied from 64% of the total zinc at station 3 to 98% of the TR at the seep (Table 4).

Table 5 summarizes the dissolved concentrations of metals found at all polluted stations and compares them to maximum suggested concentrations for fish and other aquatic life and USPHS drinking water standards (Wentz, 1974). Zinc was above these suggested standards at all polluted stations sampled. Only at stations 2 and 3 was dissolved cadmium in concentrations above these limits. The concentrations found for this parameter ranged from 0.18-0.30 mg/l. Dissolved copper exceeded these standards at station 2 during both sampling periods but only during June at station 5. The concentration found for this metal at these two stations was 0.01 mg/l. Dissolved iron was found above the maximum level suggested by Wentz (1974) once during the study period. A concentration of 11.0 mg/l dissolved iron at station 2 exceeded this limit on 6 June (Table 4). This parameter was reduced to a concentration of 0.15 mg/l on the second sampling period. This considerable change in dissolved iron was due to an increase in the pH at this station. Arsenic was detected in low concentrations (0.003 mg/l maximum at station 2) but it did not exceed the suggested limit for drinking water of 0.05 mg/l.

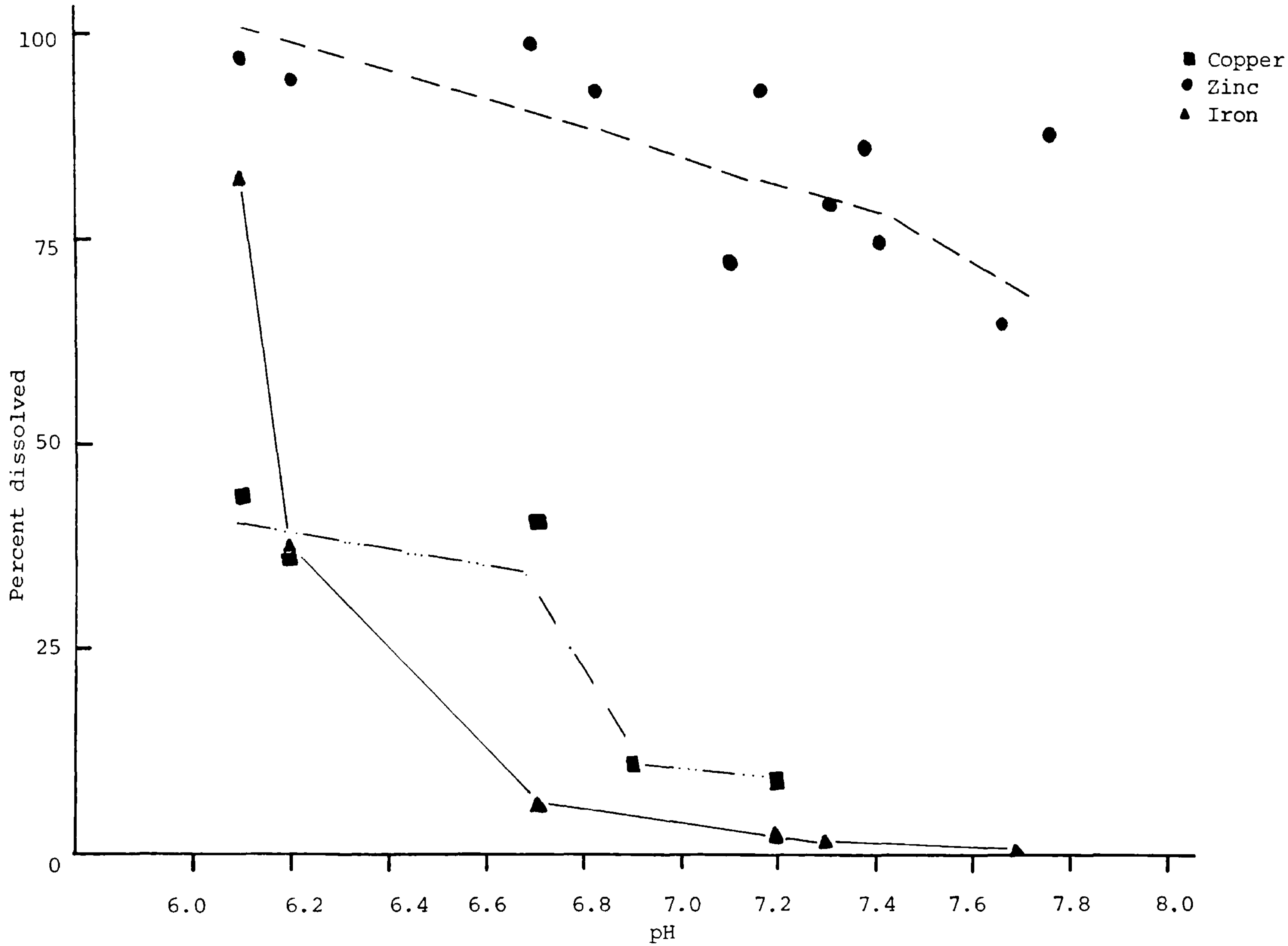


Figure 12. Behavior of heavy metals with respect to pH concentrations in the Headwater streams of the Blackfoot River.

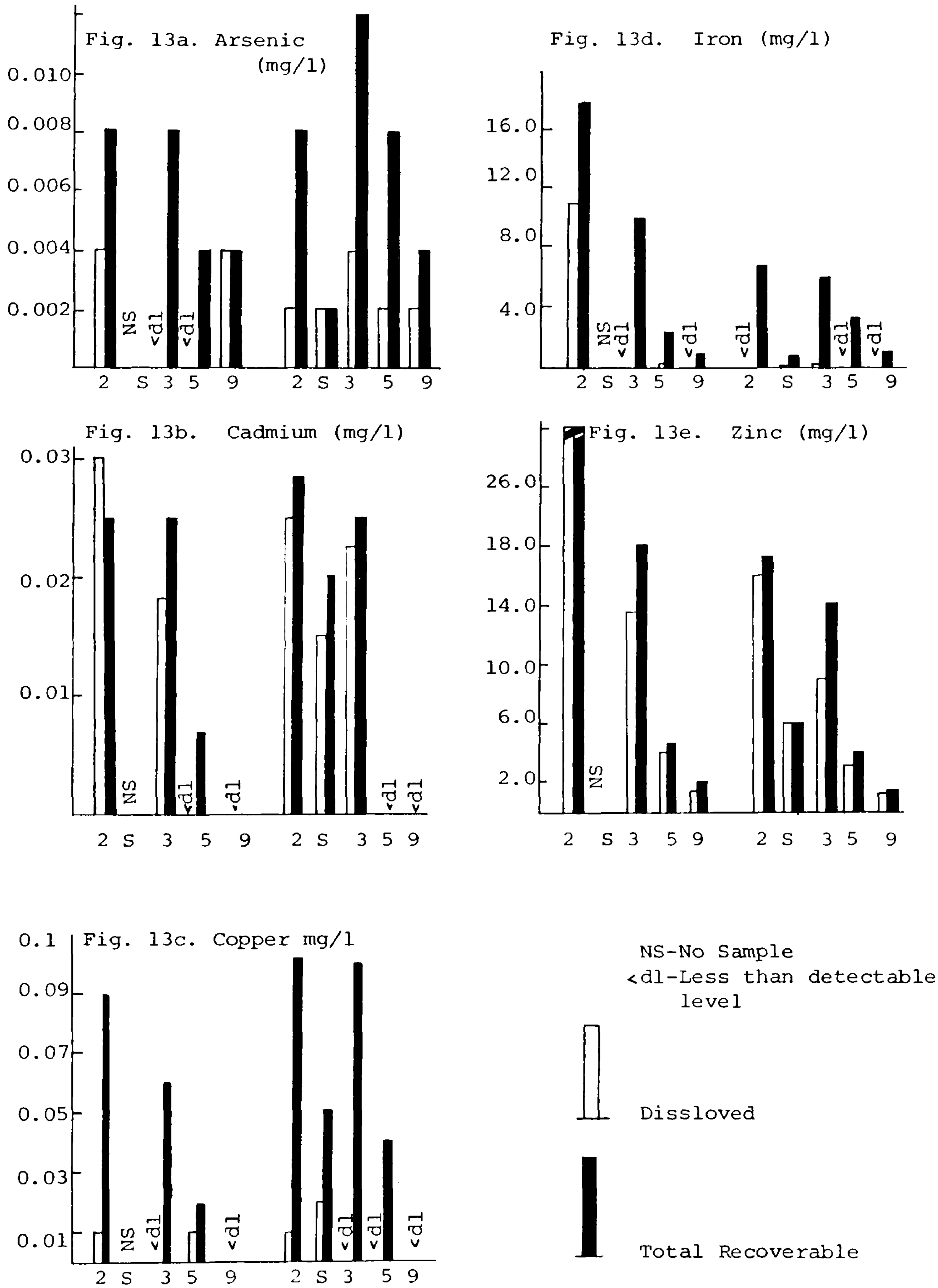


Figure 13a-e. Comparison of dissloved and total recoverable arsenic, cadmium, copper, iron, and zinc at the polluted stations-2,3,5,9, and the seep.

Table 4. Percent dissolved metals for the polluted stations, mine, 2, seep, 3, 5, and 9.

Metal		mine	2	seep	3	5	9
Arsenic	6/06/77	25%	50%	NS	<dl*	<dl	100%
	7/29/77	33%	25%	100%	20%	25%	50%
Cadmium	6/06/77	93%	100%	NS	72%	<dl	<dl
	7/29/77	100%	89%	75%	88%	<dl	<dl
Copper	6/06/77	43%	11%	NS	<dl	50%	<dl
	7/29/77	36%	9%	40%	<dl	<dl	<dl
Iron	6/06/77	80%	61%	NS	dl	1%	<dl
	7/29/77	37%	2%	50%	.5%	<dl	26%
Lead		below detectable limit during both sampling periods					
Zinc	6/06/77	97%	93%	NS	72%	81%	88%
	7/29/77	95%	94%	98%	64%	75%	86%

*detectable limit

Table 5. Comparison of dissolved heavy metal parameters and suggested limits for aquatic life and pottable water in mg/l.

Water parameter		mine	2	seep	3	5	9	Max. suggested conc. for fish & aquatic life*	USPHS Drinking water standards
Arsenic	6/06/77	0.002	0.002	NS**	0.001	0.001	0.002		
	7/29/77	0.003	0.001	0.001	0.002	0.001	0.001	--	0.05
Cadmium	6/06/77	0.028	0.030	NS	0.018	0.001	0.001		
	7/29/77	0.035	0.025	0.015	0.022	0.001	0.001	0.01	0.01 CR***
Copper	6/06/77	0.06	0.01	NS	0.01	0.01	0.01		
	7/29/77	0.05	0.01	0.02	0.01	0.01	0.01	0.01-0.02	1.0 SL****
Iron	6/06/77	21.0	11.0	NS	0.02	0.03	0.02		
	7/29/77	2.8	0.15	0.02	0.03	0.02	0.18	0.03	0.3 SL
Lead		All stations during both sampling periods below 0.05							
Zinc	6/06/77	38.0	27.0	NS	13.0	3.5	1.5		
	7/29/77	20.0	16.0	5.9	8.9	3.0	1.2	0.03-0.07	5.0 SL

*Wentz, 1974
**No sample taken
***Cause for rejection limit
****Suggested limit

Dissolved oxygen, temperature, pH, and hardness are known to effect the solubility of heavy metal behavior in water. Figure 12 illustrates a progression of heavy metal precipitation with a rising pH in the Blackfoot River headwaters. Zinc, copper, and iron solubility was directly correlated with a change in the pH of the waters during the sampling period. All of the iron was precipitated with a pH greater than 7.7. The solubility of arsenic and cadmium was negatively correlated with pH. As the pH of water is increased, the metals are reduced to their insoluble forms which causes precipitation.

In acid mine streams, the adverse effect of total iron is one of sedimentation rather than toxicity. Total iron above 0.5 mg/l is considered a characteristic of acid mine drainage (Nichlos and Bulow, 1973). This concentration was exceeded at stations 2, 3, 5, 9, and the seep during both sampling periods (Figure 11d). Station 2 exhibited the highest levels (7.0 to 18.0 mg/l) of total iron. Lowest concentrations of 0.69 to 0.71 mg/l were found at station 9. Concentrations varied from 5.7 to 5.9 mg/l and 2.2 to 3.0 mg/l at stations 3 and 5, respectively. The concentration at the seep was 0.6 mg/l of total iron in the July sample.

In summary, several noteworthy chemical and physical observations can be made concerning the unpolluted and polluted station's water quality in the headwater area of the Blackfoot River.

At the unpolluted stations, 4, 6, and 7, temperature and dissolved oxygen exhibited an inverse correlation throughout the study period as did total alkalinity and total hardness. Nitrate concentrations were higher at station 4, apparently as a result of the impoundment above this station. Except for zinc at station 4, there were no concentrations of heavy metals, dissolved or total recoverable, which exceeded the recommended limits for fish and other aquatic life suggested by Wentz (1974).

Various chemical differences were observed when the results from the polluted stations (1, 2, 3, 5, 9, and the seep) are compared with those of the unpolluted stations. Specific conductivity, total hardness, and sulfate concentrations were found in higher concentrations at the polluted stations. A decrease in these parameters occurred as distance from the mine mouth increased. pH was never found below 6.0 at the polluted stations, and again, an increase in pH was observed as distance from the mine increased. Highest concentrations of all the heavy metals were analyzed from water discharged from the Mike Horse Mine. A decrease in the concentrations of these metals was apparent as distance from the mine increased.

Dissolved zinc was in excess of the suggested limits for fish and other aquatic life at the polluted stations throughout the study. Concentrations ranged from a high of 27 mg/l at the station directly below the mine to 1.5 mg/l at station 9. Dissolved copper and cadmium at the first two stations also exceeded the suggested limits for fish and other aquatic life recommended by Wentz (1974).

It is apparent from the water chemistry data that the Mike Horse Mine is the only detectable source of acid mine pollution in the Blackfoot River headwater area and the alterations in the water because of this pollution have the potential of creating a toxic environment for aquatic life.

Biotic Characteristics

Benthic Algal Species Composition

During the study period of May to September 1977, qualitative benthic algal collections were taken at each site. A list of these species by station is given in Table 6. Sixty-nine percent of the species collected were in the phylum Chrysophyta (Bacillariophyceae) and 21% were from the Chlorophyta. Seven percent were from the phylum Cyanophyta and 2% were in the Rhodophyta. A breakdown by phylum at each station is shown in Figure 14. Representatives from all four phyla were only found at stations 6 and 7.

At all stations, the majority of the species were from the phyla, Chrysophyta (Bacillariophyceae). At station 6, 74% of the species collected were from this phyla, 13% from the Chlorophyta, 9% from the Cyanophyta, and 4% were from the Rhodophyta. Sixty-seven percent of the species found at station 7 were from the Bacillariophyceae, 17% from the Chlorophyta, and 8% each from the Rhodophyta and Cyanophyta. The Bacillariophyceae contributed 74% of the species at station 4, 21% were from the Chlorophyta, and 5% from the Cyanophyta. Chlorophyta was the only phylum represented at stations 2 and 3. Bacillariophyceae and Chlorophyta were the only phyla collected at stations 1, 5, and 9. At stations 1 and 5, contributions from these phyla were 25% from the Chlorophyta and 75% from the Bacillariophyceae. A more even distribution of species between these two phylum was collected at station 9. Forty-two percent of the species collected were from the Chlorophyta and 58% were from the Bacillariophyceae.

Table 6. Occurrence of Algal Species by Site

Species	6	7	4	1	2	seep	3	5	9
Microspora stagnorum	x	x							
Stigeoclonium lubricum	x	x							
Spirogyra sp.	x	x							
Diatoma vulgare var. breve	x	x	x						
Meridion circulare	x	x	x					1	
Fragilaria sp.	x								
Hannaea arcus	x	x	1						1
Synedra ulna	x	x	x					x	1
Synedra rupems var. scotia	x								
Achnanthes minutissima var. minutissima	x	x							
Frustulia rhomboides var. rhomboides	x								
Navicula sp (14x4)	x	x	x	x				x	
Navicula sp. (25/3)	x	x	x						x
N. notha var. notha	x	x	x						x
N. cryptocephala var. cryptocephala	x	x							
Pinnularia sp.	x								
Cymbella minuta var. silesiaca	x	x	x						
C. affinis var. affinis	x								
C. mexicana	x	x							
C. prostrata var. auerswaldii	x	x	x					1	
Oscillatoria sp.	x	x	x						
Nostoc pruniforme	x	x							
Batrachospermum sp.	x	x							
Gomphonema sp.		x							
Ulothrix cylindricum			x	x		x		x	x
Schizomeris Leibleinii			x						x
Spirogyra porticalis			x					x	
Synedra radians var. radians			x						x
Synedra incisa			1						1
Achnanthes microcephala			x	x		x		x	x
Anomoeoneis vitrea var. vitrea			x					x	x
Navicula pupula var. capitata			x	x		x		x	x
Gomphonema olivaceoides var. densestrita			x						

Species	6	7	4	1	2	seep	3	5	9
G. truncatum var. capitatum			x					x	
Microspora quadrata			x			x		x	x
Stigeoclonium sp.			x					x	x
Oscillatoria subbrevis				1					
Chlorella sp.??					x		x		
Diatoma anceps var. anceps			x						
Eunotia tenella								x	x
Rhizoclonium heiroglyphicum									x

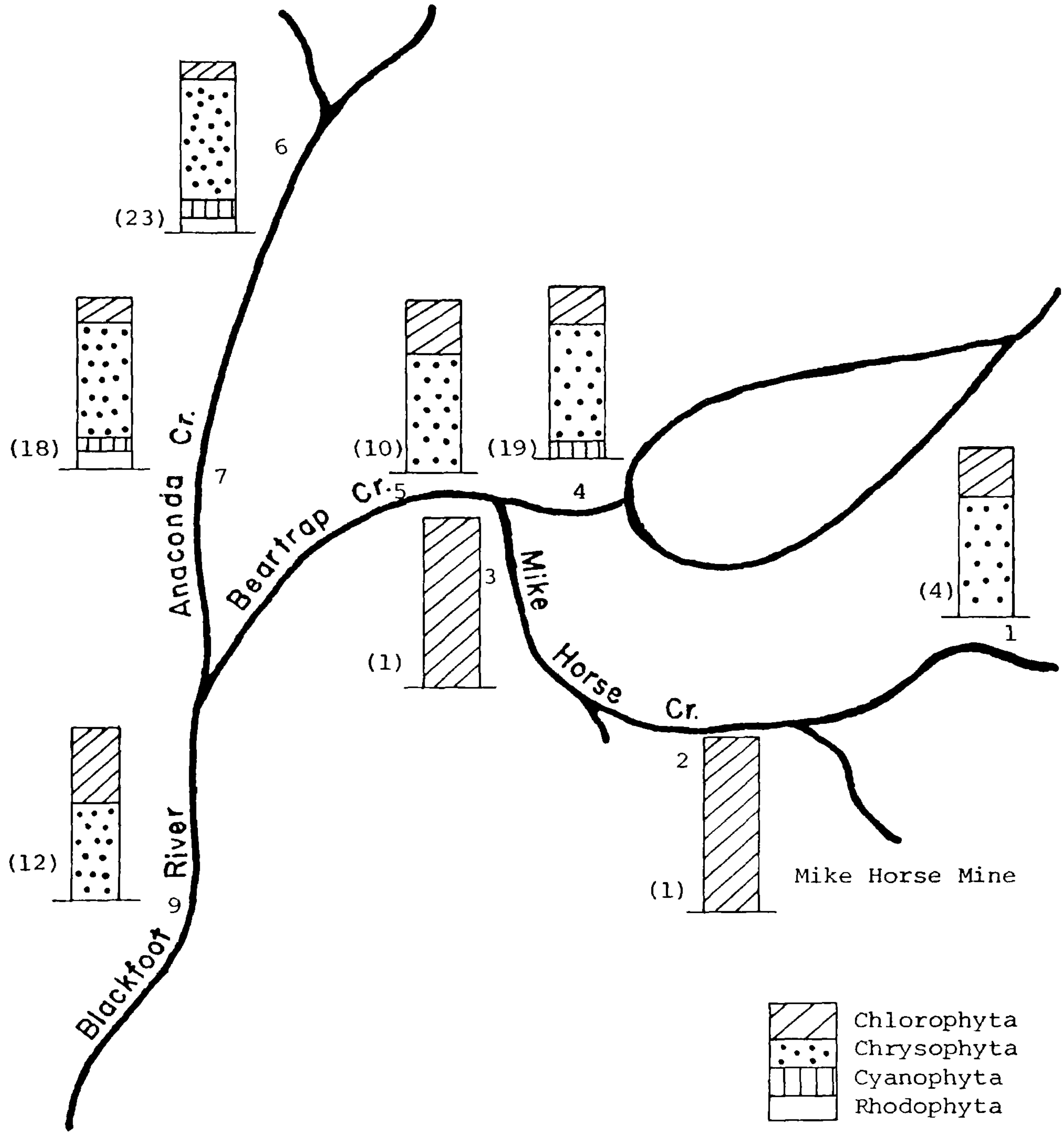


Figure 14. Percent of algal species per phylum. Numbers in parentheses signify total numbers of species collected at each station.

In a study of acid mine waters in West Virginia, Bennett (1969) reported 46% of the species inhabiting these waters were from the Chlorophyta, 46% from Chrysophyta, 8% from Euglenophyta, 3% from Pyrrophyta, and 4% from the Cyanophyta. He found the orders Ulotrichales and Microsporales, from the Chlorophyta, to be tolerant to acid mine pollution. Whitton (1974) concluded that Ulotrichales and Zygnemales were relatively resistant to zinc, copper, and lead. He found Spirogyrales to exhibit a great range in their resistance to zinc. Species from the Ulotrichales, Microsporales, and Spirogyrales were all found in waters affected by acid mine drainage during this study (stations 1, 5, 9, and the seep).

A total of 42 species were found during the study (Table 6). Station 6 had the highest number of species of 23 (55% of the total number were found here). Station 4 had 19 species (45%) and station 7 had 18 species (42%). Stations 1, 5, and 9 had 5 (12%0, 10 (23%), and 11 (26%), respectively. Chlorella sp. was the only species found at stations 2 and 3 during the entire study. Except for one species of Gomphonema, all species collected at station 7 were also present at station 6. There were no species collected at the polluted sites that were not found at either station 6, 7, or 4.

Algal Species and Heavy Metal Concentrations

The total number of algal species were inversely correlated with total iron and dissolved zinc, cadmium, and copper (Figure 15). The greatest number of species were found at stations 4, 6, and 7 during the entire study period. At these stations, metal concentrations

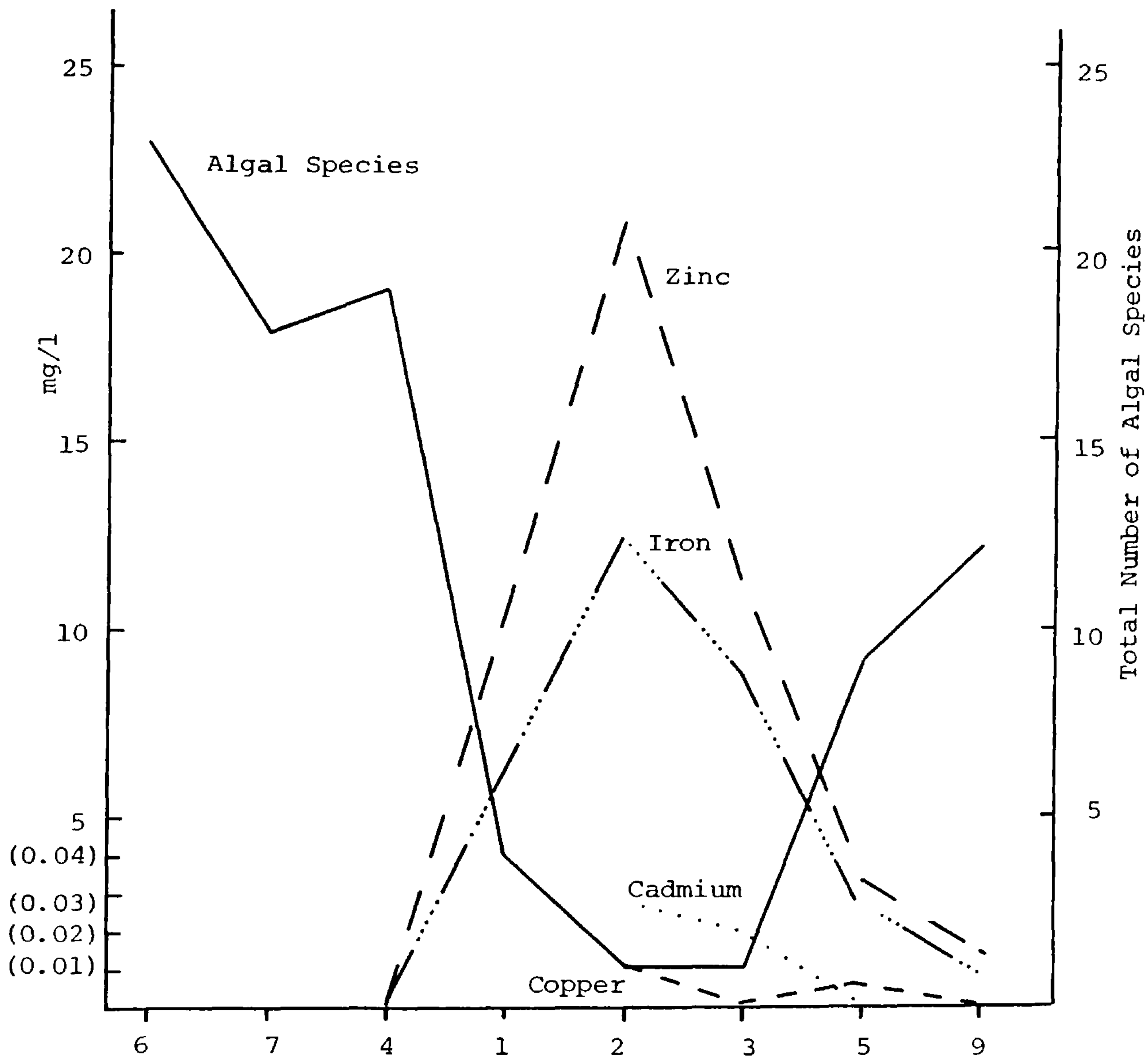


Figure 15. Total algal species by station versus average dissolved zinc, copper, cadmium, and total recoverable iron (expanded scale for copper and cadmium concentrations).

were either undetectable or at extremely low levels. Except for zinc at station 4, the unpolluted stations' heavy metal concentrations did not exceed the suggested limits for fish and other aquatic life (Wentz, 1974).

Total iron and dissolved zinc were present at detectable levels at stations 2, 3, 5, 9, and the seep. These concentrations exceeded the recommended standards for fish and other aquatic life suggested by Wentz (1974). As the distance from the mine increased, these concentrations decreased, and the total number of algal species increased (Figure 14). Dissolved copper exceeded Wentz's standards at station 2 during both sampling periods, and at station 5 during the first sample in June. Cadmium exceeded these limits at stations 2 and 3 during both sampling periods. It is difficult to distinguish a possible synergistic effect between these two metals and zinc because of dissolved zinc being in concentrations 50-2,700 times greater at stations 2, 3, 5, and 9 than the copper and cadmium concentrations.

In comparing the stations and their respective dissolved zinc, total iron concentrations, and algal species, a natural distribution was evident (Table 7). An extremely resistant group occurred in waters having zinc concentrations of 8.9 to 16.0 mg/l and iron at 5.7-9.7 mg/l. Only one species represented this group. The next group occurred in waters having zinc concentrations of 3.5 to 6.0 mg/l and iron at 0.6 mg/l. This group was categorized very resistant and four species possessed very resistant characteristics. A resistant group contained seven species and were found in waters of 3.0 to

Table 7. Species composition by concentration of dissolved zinc and total iron in mg/l.

Extremely resistant	Very resistant	Resistant
Zinc 8.9-16.0 mg/l	Zinc 3.5-6.0 mg/l	Zinc 3.0-3.5 mg/l
Iron 5.7-9.7 mg/l	Iron 0.6 mg/l	Iron 2.2-3.0 mg/l
Chorella sp.	Microspora quadrata	Stigeoclonium sp.
	Ulothrix cylindricum	Spirogyra porticalis
	Achnanthes microcephala var. microcephala	Anomoeoneis vitrea var. vitrea
	Navicula pupula var. capitata	Eunotia tenella
		Gomphonema truncatum var. capitatum
		Navicula sp.
		Synedra ulna

Moderately resistant	Low resistant	Very low resistant
Zinc 1.0-2.0 mg/l	Zinc 0.13-0.21 mg/l	Zinc 0.02 mg/l
Iron 0.70 mg/l	Iron 0.05-0.10 mg/l	Iron 0.02 mg/l
Rhizoclonium heirglyphicum	Cymbella minuta var. silesiaca	Microspora stagnorum
Schizomeris Leibleinii	Cymbella prostrata var. auerswaldii	Stigeoclonium lubricum
Navicula sp.	Diatoma anceps var. anceps	Spirogyra sp.
Navicula notha var. notha	Gomphonema olivaceoides var. densestrita	Achnanthes minutissima var. minutissima
Synedra incisa	Meridion circulare	Cymbella affinis var. affinis
Synedra radians var. radians	Oscillatoria sp.	Cymbella mexicana var. mexicana
Synedra rupems var. scotica		Fragilaria sp.
		Frustulia rhomboides var. rhomboides
		Gomphonema sp.
		Hannaea arcus
		Navicula cryptocephala var. crytocephala
		Pinnularia sp.
		Nostoc pruniformes
		Batrachospermum sp.

3.5 mg/l for zinc and 2.2 to 3.0 mg/l for iron. The seven species categorized as moderately resistant were able to tolerate concentrations of 1.0 to 2.0 mg/l zinc and 0.70 mg/l iron. Seven algal species inhabiting waters with concentrations of zinc of 0.13-0.21 mg/l and total concentrations of iron of 0.05 to 0.10 mg/l were considered low in resistance. Fourteen species unable to tolerate water with concentrations of zinc and iron above 0.02 mg/l were considered very low in resistance.

Habitat Preference for Benthic Algal Species

Algal species collected at stations 1 through 9 and the seep are listed in order of their resistance to zinc and iron. Published habitat preferences and descriptions and habitat characteristics of the Blackfoot River headwater area are included.

Extremely resistant-Zinc 8.9-16.0 mg/l
Iron 5.7-9.7 mg/l

Chlorella sp.-C. vulgaris was found to be tolerant of lead, copper, and zinc by Antonovics, et al. (1971). Bennett (1969) found C. vulgaris contributing small populations to acid creeks in West Virginia. The species collected at stations 2 and 3 was able to grow in extremely reduced numbers within the ferric hydroxide precipitate. This species was collected during all the sampling periods at station 3 but only at station 2 after July.

Very resistant-Zinc 3.5-6.0 mg/l
Iron 0.6 mg/l

Microspora quadrata-Bennett (1969) collected M. quadrata in small populations in acid mine waters. Smith (1942) also found this species in waters with a low pH. Two unidentified species of Microspora have been found to be tolerant of zinc in concentrations of 4.0-4.9 mg/l by Whitton (1970). Another unidentified species was found by McLean and Jones (1975) to be absent from areas with zinc concentrations of 2.0 to 4.0 mg/l. M. quadrata was found abundantly at stations 4, 5, 9 and the seep during the study period. It was able to tolerate zinc concentrations up to 6.0 mg/l and copper levels of 0.02 mg/l without the ferric hydroxide precipitate. It also inhabited water with zinc concentrations of 3.0-3.5 mg/l and total iron of 2.2 to 3.0 mg/l but copper concentrations below the detectable limit.

Achnanthes microcephala var. microcephala-This diatom was found in abundant populations in rivers polluted by acid mine drainage with a pH of 5.0-6.6 (Reese, 1937). No specific concentrations were given for the metal concentrations in this river but zinc and lead were reported to be present. In the NW Miramichi River in New Brunswick, this species was found in waters with a 10 mg/l zinc concentration (Besch and Cantin, 1974). It was generally the most abundant species at the polluted sites in the Miramichi if the pH was above 5.0. A. microcephala was found at stations 1, 4, 5, 9, and the seep throughout the study. This occurrence substantiates the evidence that A. microcephala may be a good indicator of waters polluted with high concentrations of zinc.

Navicula pupula var. capitata-This species has been found to be indifferent to current and pH within a range of 5.7-9.0 and cosmopolitan (Lowe, 1974). Patrick and Reimer (1966) found this species to prefer fresh, circumneutral waters of fairly high mineral content. In Besch and Cantin's study (1974), they reported this species to be present only in waters with a high specific conductivity. The occurrence of this species in waters high in specific conductivity during this study supports the published findings given above.

Ulothrix cylindricum-Species of Ulothrix have been well documented as the dominant algae in acid mine waters and waters polluted by high levels of zinc. Warner (1971) and Bennett (1969) collected Ulothrix tenerrima in streams with a low pH and ferric hydroxide precipitate. This same species was observed by Moore and Clarkson (1967) in an acid mine stream with a pH of 4.0. Lackey (1938) collected U. zonata in acid mine waters. McLean and Jones (1975) found a species of Ulothrix as the dominant species in the Ystwyth River in Wales where zinc concentrations were between 0.88 and 2.1 mg/l, copper at 0.02 mg/l and total iron concentrations of 0.2-0.4 mg/l. Whitton (1970) concluded the Ulothrichales, in general, were relatively resistant to zinc in concentrations from 0.70 to 3.00 mg/l. A species of Ulothrix was collected by Whitton and Morgan (unpublished) in streams in northern Wales where concentrations of zinc were 0.01 to 4.0 mg/l. U. cylindricum was the dominant species in the seep as well as stations 1, 3, 5, and 9 throughout the study period. It was also found at station 4, an unpolluted station.

Resistant-Zinc 3.0-3.5 mg/l
Iron 2.2-3.0 mg/l

Stigeoclonium sp.-An unidentified species of Stigeoclonium was found in the zinc polluted NW Miramichi River by Besch and Cantin (1974). S. tenue has been reported as having an intermediate resistance (1.0 mg/l) to zinc (Whitton, 1970). Various species have also been collected in acid mine waters by Lackey (1938), Warner (1971), and Mackenthum (1969). Stigeoclonium sp. was only found during the June sample at stations 4, 5, and 9. The disappearance of these species after June was not due to an increase in the metal concentrations at these stations. It may have been caused by either an increase in light and temperature or a decrease in discharge.

Spirogyra porticalis-Unidentified species of Spirogyra have been found tolerant to zinc in concentrations of 0.2 to 4.0 mg/l by Whitton (1970). Mount and Williams (1965) concluded that Spirogyra was highly tolerant to relatively large concentrations of zinc. Jones (1958) collected Spirogyra sp. in waters with zinc concentrations of 0.2 to 1.2 mg/l. Blum (1956) reported species of Spirogyra, in general, to grow optimally when current was at a minimum. S. porticalis was collected at stations 4 and 5 only during September. During this sampling, period velocity had decreased to the lowest recorded levels at these two stations.

Anomoeoneis vitrea var. vitrea-This species has been collected in a wide range of waters but seems to prefer slightly alkaline waters (Patrick and Reimer, 1966). Lowe (1974) also found this species indifferent to most water parameters and was cosmopolitan. A. vitrea was collected at stations 4, 5, and 9 throughout the study period but in extremely low populations. The presence of this species at stations 5 and 9 may have been due to drift from station 4.

Eunotia tenella-Patrick and Reimer (1966) reported this species to be found in somewhat acid, slightly soft waters. E. tenella was found by Bennett (1969) to be very abundant in acid creeks in West Virginia. This species was collected at stations 5 and 9 during the entire study period. It was common in the September collection at station 9.

Gomphonema truncatum var. capitatum-Patrick and Reimer (1975) reported this species to be common in shallow, fresh water. G. truncatum was collected at stations 4 and 5 and may have been a transient at station 5. Its absence from collections at station 9 supports this conclusion.

Synedra ulna-This species has been reported to be found in slightly alkaline waters with a pH of 7.0-8.0 (Lowe, 1974). Patrick and Reimer (1966) reported S. ulna to be cosmopolitan. Besch and Cantin (1974) collected this species in waters with zinc concentrations ranging from 1-2 mg/l. S. ulna was also reported by Mount and Williams (1965) to be highly tolerant to relatively high concentrations of zinc. S. ulna was collected at all stations except stations 1, 2, 3, and the seep in the study area. It was not found in the June sampling at stations where zinc concentrations were greater than 3.5 mg/l and copper was 0.01 mg/l.

Moderately resistant-Zinc 1.2-1.5 mg/l
Iron 0.69-0.71 mg/l

Rhizoclonium heiroglyphicum-This species has been reported to be common in standing hard waters (Prescott, 1962). Warner (1971) collected a species of Rhizoclonium in acid mine waters with a pH of 3.1-6.6. R. heiroglyphicum was found by Weaver and Nash (1968) in acid mine waters in Pennsylvania. R. heirglyphicum was intermingled with other filamentous algae at station 9 during the June and September sample.

Schizomeris Leibleinii-This species has been collected in soft and hard waters in shallow and marsh-like margins (Prescott, 1962). S. Leibleinii was found intertwined with other filamentous Chlorophytes at stations 4 and 9 during the study period. It was only collected during lowest observed discharge.

Navicula notha var. notha-Lowe (1974) found this species in water with a low mineral content. Patrick and Reimer (1966) reported it in similar waters. N. notha was collected at various times during the study period at stations 4, 6, and 7 but was found at all sampling collections at station 9.

Synedra incisa-This species has been collected in fresh water (Patrick and Reimer, 1966). S. incisa was found in extremely low populations at stations 4 and 9 during September.

Synedra radians var. radians-Lowe (1974) reported this species to be alkalinphilous, cosmopolitan, and often in water with a fairly high mineral content. This species was collected throughout the study at station 4 but only in the September collections of station 9. Both stations had specific conductivity readings between 260-360 µhos/cm. At these two stations, the pH ranged from 7.3-7.8.

Synedra rumpens var. scotica-Patrick and Reimer (1966) collected this species in fresh water of low mineral content. Besch and Cantin (1974) found S. rupems in waters with a pH of 6.4 to 8.0 and zinc concentrations up to 1.0 mg/l. They found its abundance to be low at zinc concentrations higher than this. Bennett (1969) found this species growing abundantly in acid mine waters of West Virginia. S. rumpens was collected in July at station 6 and during May and June at station 9.

Low resistant-Zinc 0.13-0.21 mg/l
Iron 0.05-0.10 mg/l

Cymbella minuta var. silesiaca-Patrick and Reimer (1975) found this species to be widespread, pH indifferent, and oligohalobous. This species was collected most frequently at station 4 but also occurred at stations 6 and 7. The pH at these three stations ranged from 7.2 to 7.9.

Diatoma anceps var. anceps-Patrick and Reimer (1966) reported this species in cool water of low mineral content in mountainous regions. Lowe (1974) found similar habitat preferences for this species. D. anceps was collected only at station 4 and in very small populations. Mineral content was fairly high at station 4 (260-360 μhos/cm) due to the impoundment causing an increase in dissolved ions.

Diatoma vulgare var. breve-Patrick and Reimer (1966) reported this species to prefer cool water. Klarich (1976) found it to be able to withstand temperature fluctuations greater than 15°C. Blum (1956) reported D. vulgare to be characteristic of riffle areas. This species was common at stations 4, 6, and 7 throughout the study period in riffle areas. It was only found at station 4 during the September collection. Water temperatures at these three stations ranged from 8-14°C during the study period.

Gomphonema olivaceoides var. densestrita-

This species was collected at station 4 in the May sample.

Meridion circulare-Patrick and Reimer (1966) reported this species to prefer flowing, fresh water. Lowe (1974) reported it as cosmopolitan and an indicator of high oxygen levels. M. circulare was collected abundantly at stations 4, 6, and 7 where oxygen levels varied from 7.0-9.0 ppm.

Very low resistance or no resistance-Zinc <0.02 mg/l
Iron <0.02 mg/l

Microspora stagnorum-Bennett (1969) found this species to be rare in rivers and reached maximum abundance in winter in West Virginia. Prescott (1962) reported it to be common in lakes and ponds. Smith (1942) has observed M. stagnorum in water with a low pH. At stations 6 and 7, this species produced a thin layer on the rubble of the riffle areas. It was not collected in the September sample.

Stigeoclonium lubricum-This species has been reported as common in running water (Prescott, 1962). It was found growing in small tufts in the riffle areas of stations 6 and 7 from June to September.

Achnanthes minutissima var. minutissima-A. minutissima has been found to be indifferent to pH, current, calcium and iron by Lowe (1974). He also reported it to be periphytic and cosmopolitan. Large populations have been found in waters with a pH of 6.5-9.0 (Patrick and Reimer, 1966). Besch and Cantin (1974) found it characteristic of streams unpolluted by zinc mining. They collected it only occasionally in polluted stretches where zinc concentrations were 0.1-0.2 mg/l. A. minutissima was collected at stations 6 and 7 where pH ranged from 7.6-7.9. It was common in these waters throughout the study period.

Cymbella affinis var. affinis-Lowe (1974) found this species to be indifferent to current, cosmopolitan, and alkaliphilous. Besch and Cantin (1974) found this species to have a low resistance to zinc (0.1-0.2 mg/l). Klarich (1976) reported C. affinis to have a wide range of tolerance to salt. This species was collected at station 6 during May and July.

Cymbella mexicana var. mexicana-Patrick and Reimer (1975) reported this species to be widely distributed, especially throughout the northern and western United States. They reported it to prefer hard waters and may be an alkaliphil. C. mexicana was collected throughout the study period at station 6 but only during July at station 7.

Frustulia rhomboides var. rhomboides-This species has been commonly found in bogs or lakes in slightly acid water. It has also been recorded in the tropics at a pH of 7.8 (Patrick and Reimer, 1966). Besch and Cantin (1974) fount it in streams with low zinc concentrations (0.01-0.02 mg/l). Bennett (1969) reported F. rhomboides as abundant in waters polluted by acid mine drainage. This species was collected at station 6 during July and September. The pH at this station was 7.6-7.7.

Hannaea arcus var. arcus-Patrick and Reimer (1966) reported this species to inhabit cool, flowing water, particularly in mountainous regions. Klarich (1976) collected it in unpolluted stretches of the Yellowstone River, Montana. H. arcus was abundant throughout the study period at stations 6 and 7. These waters have the characteristics reported by Patrick and Reimer above.

Navicula cryptocephala var. cryptocephala-Lowe (1974) reported this species to be alkaliphilous, eutrophic, and in lakes, rivers, and bogs. Patrick and Reimer (1966) also reported a wide distribution for this species in fresh to slightly brackish water. N. cryptocephala was collected in moderate populations at stations 6 and 7 in June.

Nostoc pruniforme-Prescott (1962) found this species in hard waters and slow moving streams. Cordone and Kelley (1961) found benthic species of Nostoc to be virtually destroyed by inorganic sediment. This species was collected in May, June, and July samples at station 6. It was found at station 7 during June and July. The riffle areas of these stations had N. pruniforme adhering to the stones in from gelatinous colonies.

Batrachospermum sp.-This genus is shade tolerant, found only in cold streams in riffle areas (Blum, 1956). The carbon source for photosynthesis for this genus is carbon dioxide. Free carbon dioxide is higher in shaded waters. Therefore, Batrachospermum's shade tolerance gives it a competitive advantage over other species. This genus was collected only in the early spring and late July at stations 6 and 7. It was the dominant benthic algae at these times. Batrachospermum sp. covered the stones of Anaconda Creek with a golden hue.

Primary Productivity

Chlorophyll *a* and ash-free dry weight were used as measures of primary productivity. Because of a positive correlation between these two methods (Figure 16), only chlorophyll *a* results will be discussed in this section.

Algal species vs. chlorophyll a concentrations

Figure 17 compares total number of benthic algal species (May through September) with the average concentration of chlorophyll *a* (mg/l) for each site. Stations 6 and 7 exhibit a typical pattern of an oligotrophic mountain stream. Their total number of species was high and biomass was low. Station 4, having higher concentrations of dissolved nutrients and open banks creating an increase in radiant energy, had not only high total species numbers but also high concentrations of chlorophyll *a*. This station had the same number of species as station 7 with an average of 0.2 mg/l more chlorophyll *a*.

The effect of the impoundment on the aquatic plants at station 4 was manifested not only in the species composition of this community but also in biomass. Due to the decrease in turbidity and bank erosion below impoundments, Ward (1974) found filamentous Chlorophytes to be especially enhanced. The increase in flow constancy and nutrients due to the impoundment also benefited found species of Cladophora and Ulothrix to be the dominant species in riffles

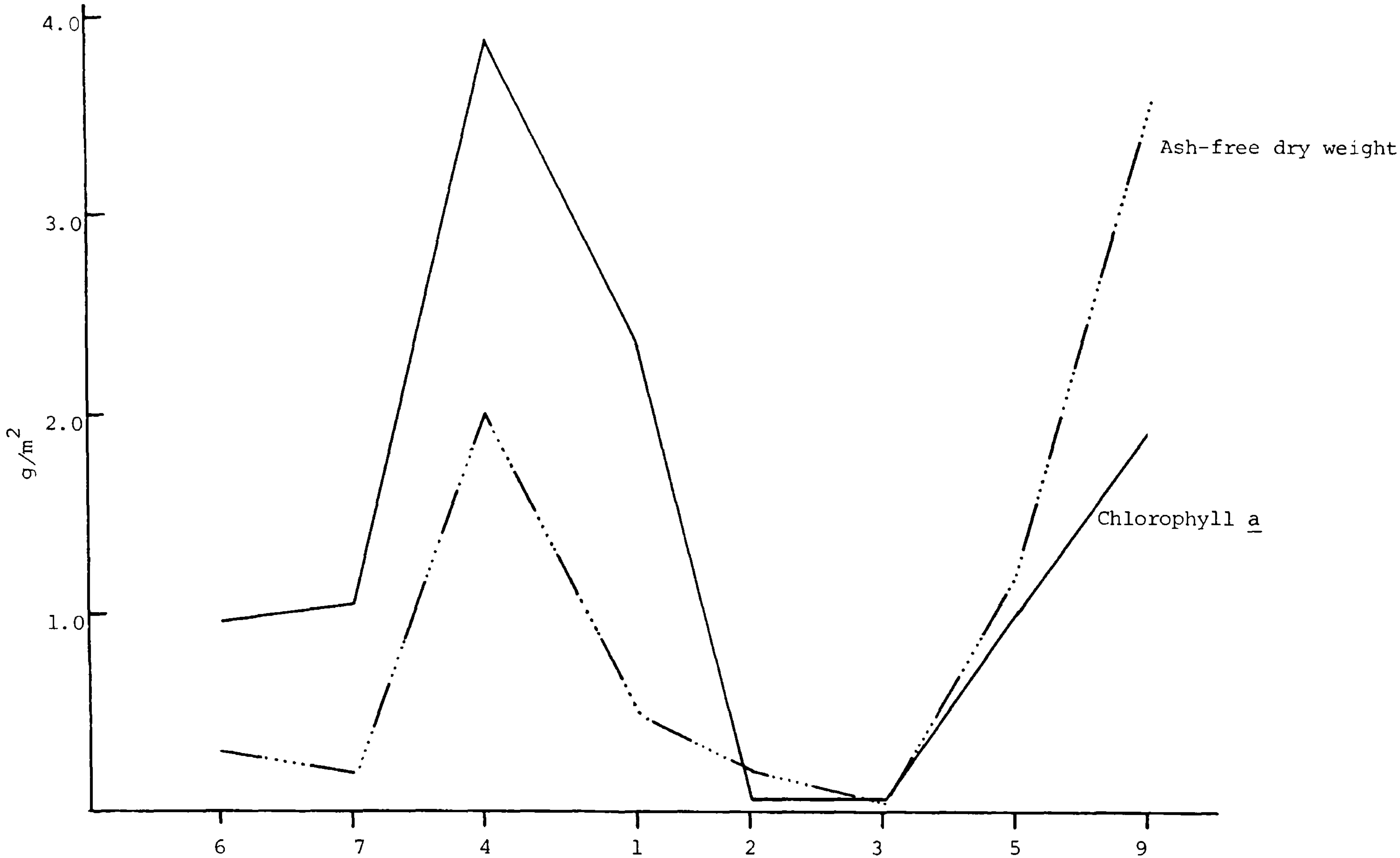


Figure 16. Average monthly chlorophyll a versus ash-free dry weight in g/m^2.

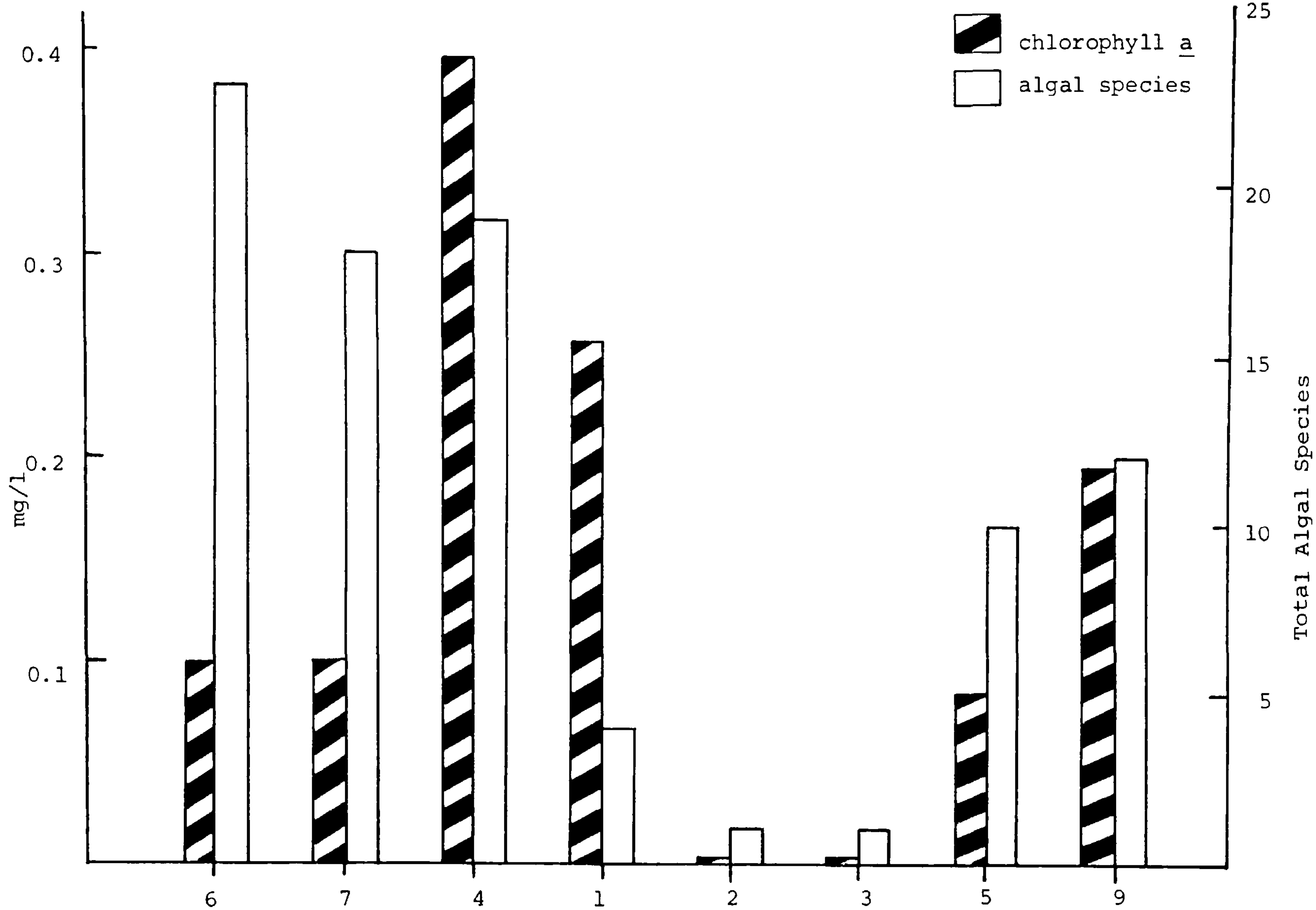


Figure 17. Total number of algal species versus chlorophyll a (mg/l) average for June, July, and August by station.

below an impoundment on the South Platte River in Colorado. Ulothrix cylindricum was collected throughout the study at station 4 but no Cladophora was collected. Blum (1956) reported Cladophora to be adversely affected by metal ions and was replaced by Stigeoclonium tenue and Spirogyra fluvaltis. Species from these genera were collected at station 4. The waters at this station were characterized by low concentrations of iron and zinc. These filamentous Chlorophytes covered 60% of the streambed during the entire study period at station 4. Cyanophytes were found to be adversely affected by impoundments (Ward, 1974). Only one species from this phylum was collected at this station and this was uncommon. Ward (1974) and Hilsenhoff (1971) reported aquatic rooted plants were also enhanced in riffle areas below impoundments. Station 4 was the only station with aquatic macrophytes growing within the streambed (see site description for station 4).

The effect on the algal populations at stations 1, 2, 3, 5, 9, and the seep was characteristic of a body of water under the stress of a toxic substance. At stations 2 and 3, only one species of algae in extremely low populations was collected. As the toxic substance(s) was diluted, (stations 5 and 9) there was an increase in the number of species. These few species were tolerant of the toxic substance and became relatively abundant, thereby increasing primary productivity.

Monthly concentrations of Chlorophyll a and Numbers of Algal Species

Unpolluted stations. At station 6 chlorophyll *a* concentrations were greatest in September (0.138 mg/l) (Figure 18a). The average for the three sampling periods was 0.102 mg/l chlorophyll *a*. The July concentration was lower than June though the levels remained fairly constant during the three sampling periods. Total algal species were inversely correlated with primary productivity, having the highest productivity and the lowest number of species during September. This may have been a result of competition or succession causing one or several species to become dominant.

The primary productivity at station 7 was similar to that of station 6 (Figure 18b). No sample could be taken at station 7 in September because of a decrease in discharge causing the three plates to become exposed to the air and dry. Chlorophyll *a* increased to 0.114 mg/l in July with an average for the two months of 0.105 mg/l. The drop in species numbers at this station in September was caused by a decreased flow. This changed the habitat from smooth flowing to a standing pool.

Highest primary productivity was found at station 4 (Figure 18c). An average of 0.389 mg/l chlorophyll *a* was calculated for the three sampling periods at this station. The concentration in July of 0.430 mg/l was the maximum level at this station. Concentrations were lowest in June. The number of species at this station remained at a constant level during the entire study period. It appears this enhancement of primary productivity was caused by the impoundment

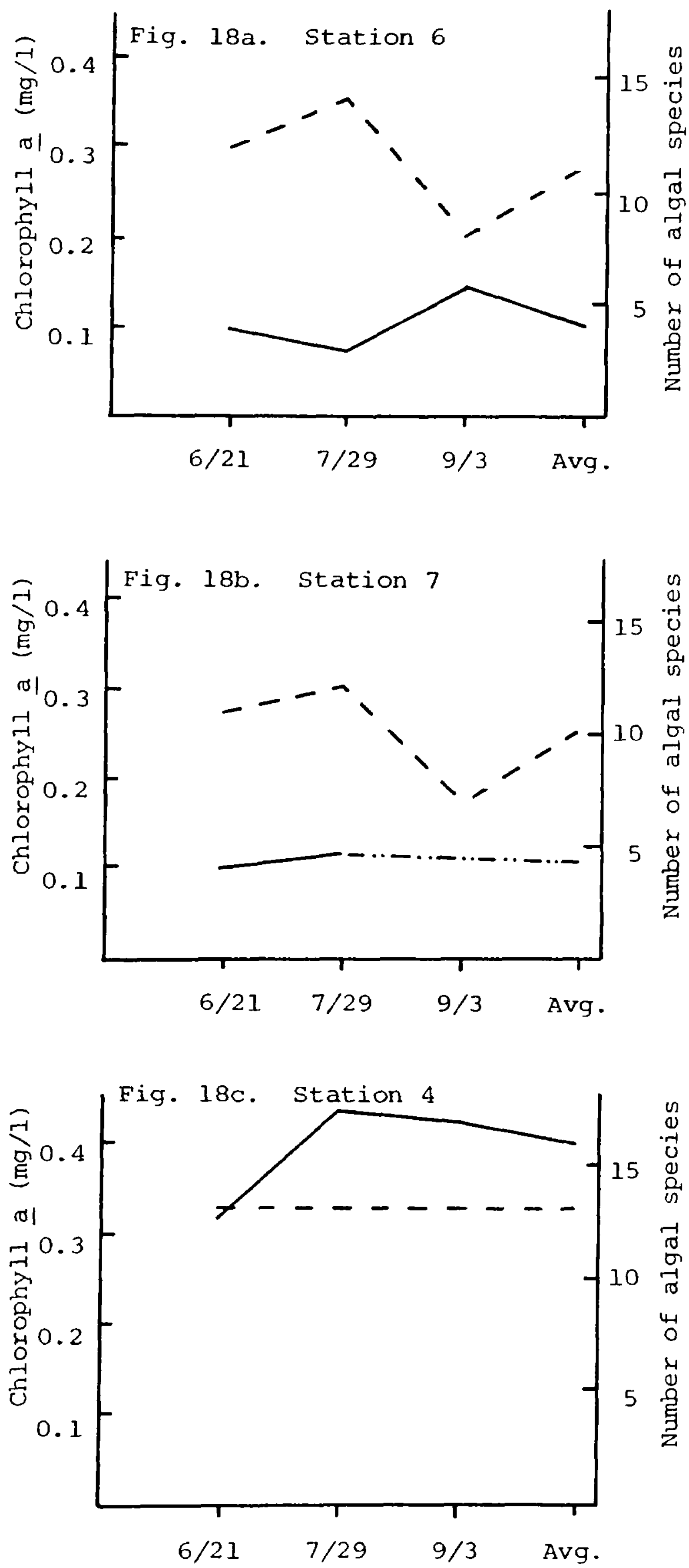


Figure 18 a-c. Chlorophyll a (mg/l) versus Total Number of Algal Species at unpolluted stations-4,6, and 7.

of the waters above this station. Several authors have found an increase in primary productivity in sections of streams below impoundments (Ward, 1974; Hilsenhoff, 1971; and Spence and Hynes, 1971). They concluded that enhancement was a consequence of an increase in nutrients and flow constancy and a decrease in turbidity and bank erosion.

Polluted stations. The stations affected by the mine pollution exhibited a longitudinal increase of chlorophyll *a* as distance from the mine increased. Station 1, above the mine, displayed the third highest level of primary productivity for all the stations (Figure 19a). The average chlorophyll *a* concentration at this station was 0.246 mg/l with similar levels in June and September. The chlorophyll *a* concentration in July was significantly lower than the other two months. The reason for this is unclear. Visible filaments of algae were present during this month at station 1 but the plates were not colonized. The productivity at this station was produced by four species of algae.

The primary productivity of stations 2 and 3 was extremely low during the three sampling periods (Figure 19b and c). Station 2 had no detectable productivity in June but increased to 0.01 and 0.017 mg/l chlorophyll *a* in July and September, respectively. Station 3 had detectable readings during the three periods of 0.008, 0.007, and 0.006 mg/l chlorophyll *a* in June, July, and September, respectively.

Primary productivity at station 5 increased throughout the duration of the study period (Figure 19d). This increase ranged

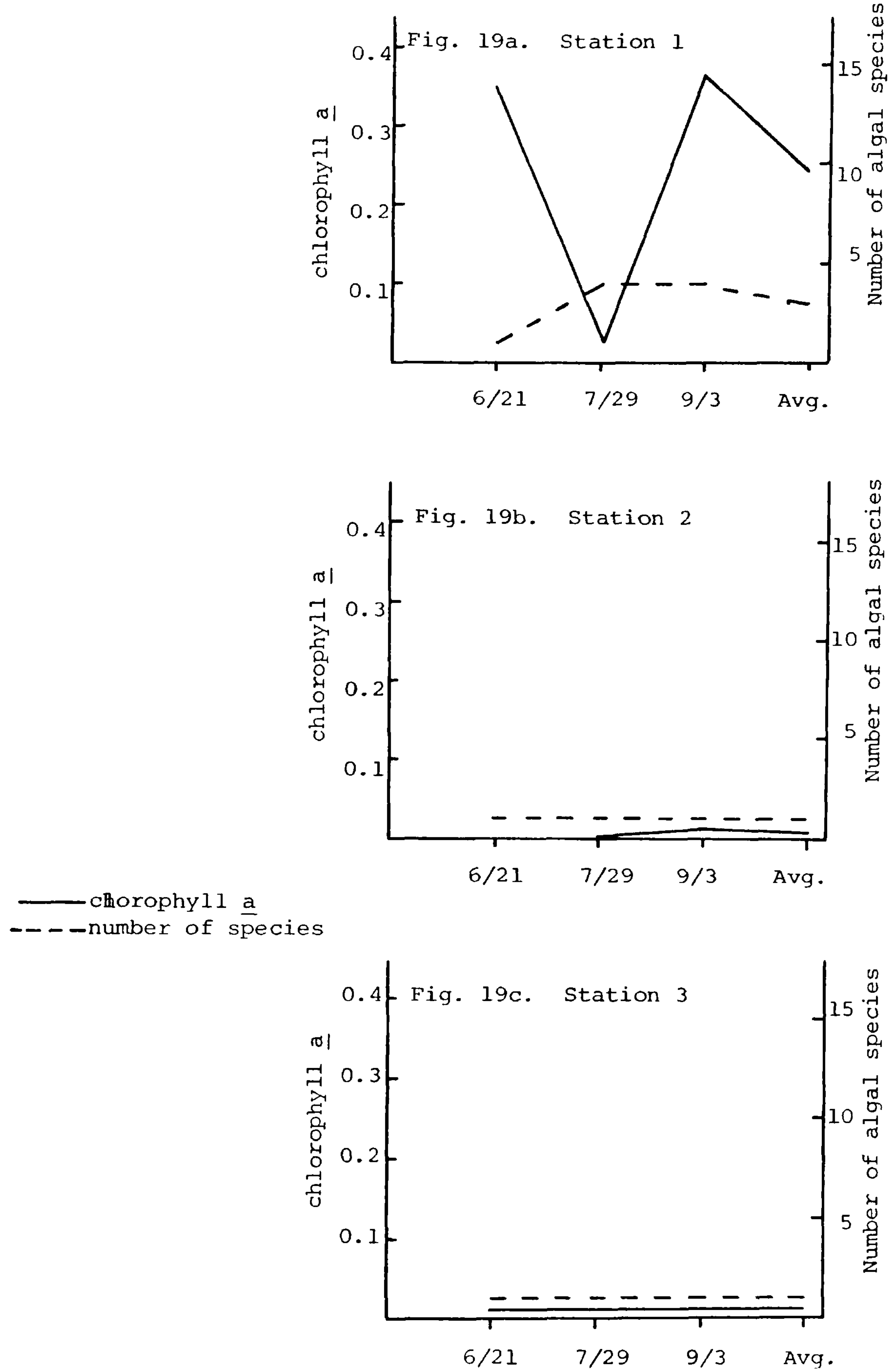


Figure 19a-c. Chlorophyll a (mg/l) versus total number of algal species at polluted stations-1,2, and 3.

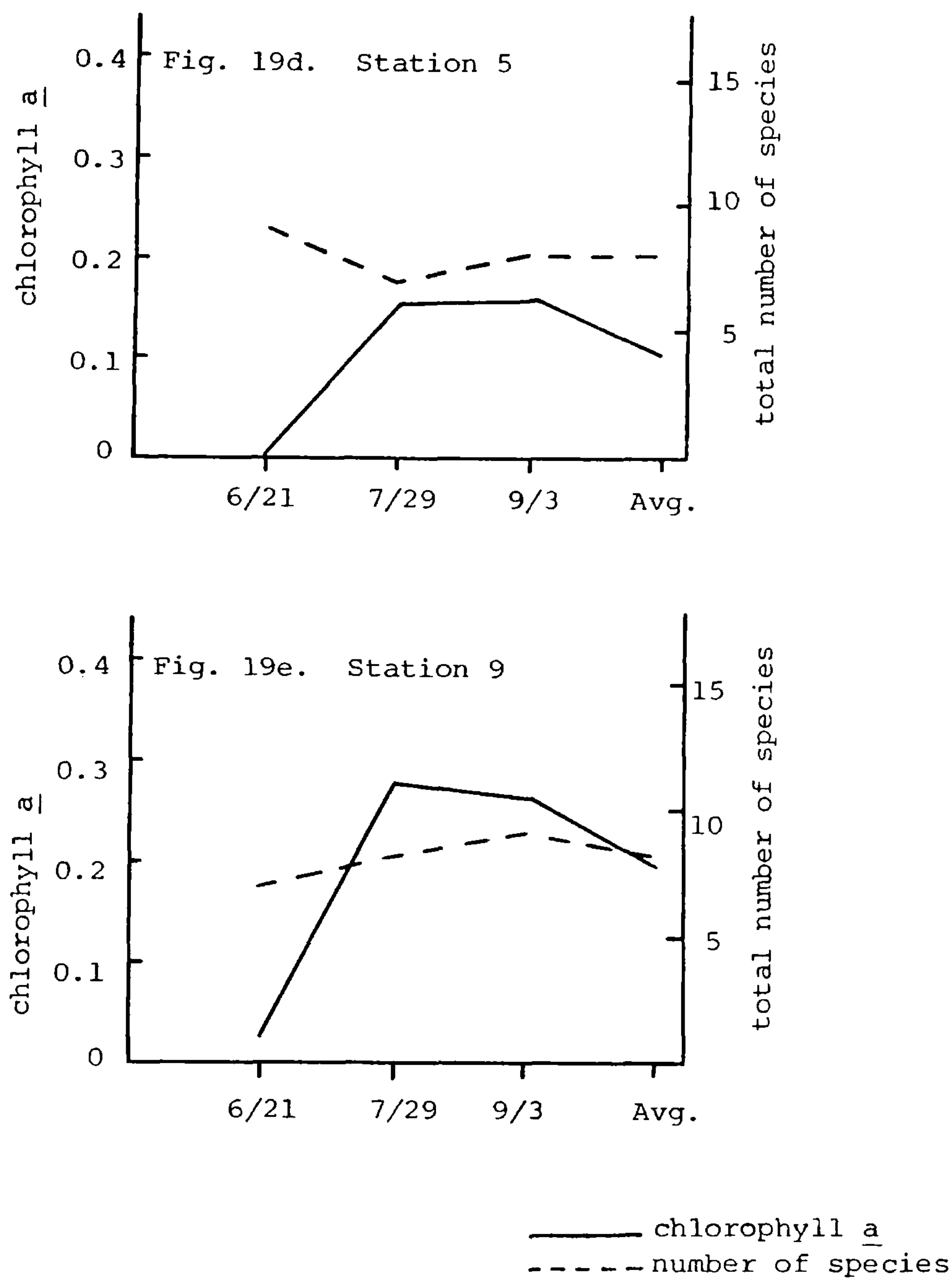


Figure 19d and e. Chlorophyll a (mg/l) versus total number of algal species at polluted stations 5 and 9.

from 0.005 mg/l chlorophyll _a_ in June to 0.127 mg/l in July. There was little change in productivity between July and September and the average concentration of chlorophyll _a_ for the three sampling periods was 0.096 mg/l. The primary productivity increased during the study, while the number of algal species decreased.

Primary productivity continued to increase at station 9 as a function of distance from the mine. Primary productivity at station 9 increased considerably from June (0.03 mg/l chlorophyll _a_) to September (0.276 mg/l). The average chlorophyll _a_ concentration for station 9 was 0.190 mg/l. Species numbers steadily increased during the three sampling periods.

Effects of Chemical and Physical Parameters on Primary Productivity

Many of the physical and chemical parameters of the water were inversely correlated with the primary productivity in the headwater area: specific conductivity, sulfate, hardness, the majority of the heavy metals, and discharge. Only the heavy metal concentrations have been documented as being harmful to aquatic life and these will be discussed in greater detail (Wentz, 1974).

Dissolved zinc and total iron were above the maximum concentrations for fish and other aquatic life suggested by Wentz (1974) at stations 2, 3, 5, and 9 (Table 5). Concentrations of these metals were inversely correlated with primary productivity (Figure 20). Although dissolved copper and cadmium concentrations exceeded the limits suggested by Wentz, their concentrations were 50-2,700 times lower than the dissolved zinc concentrations during the two sampling periods.

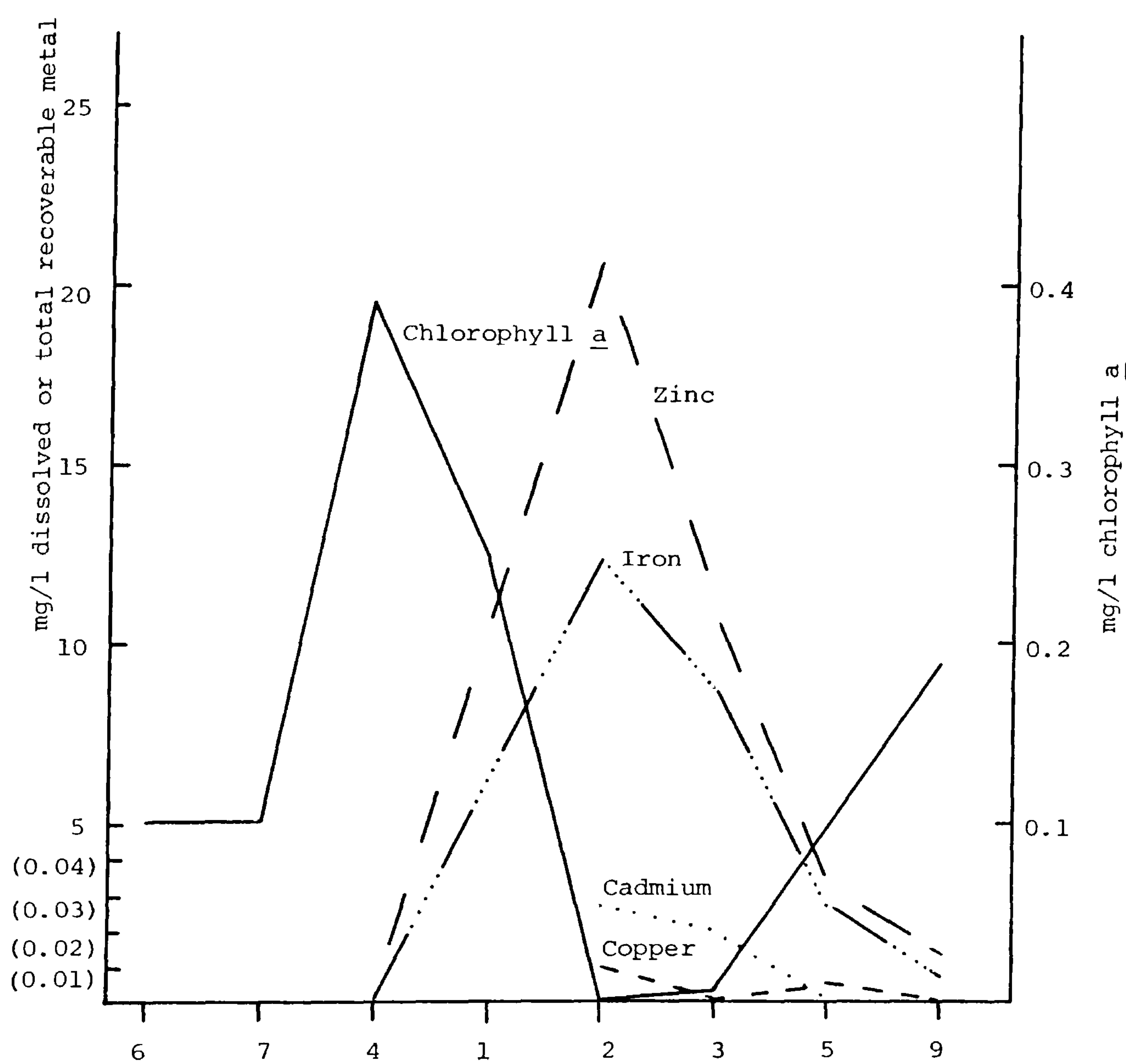


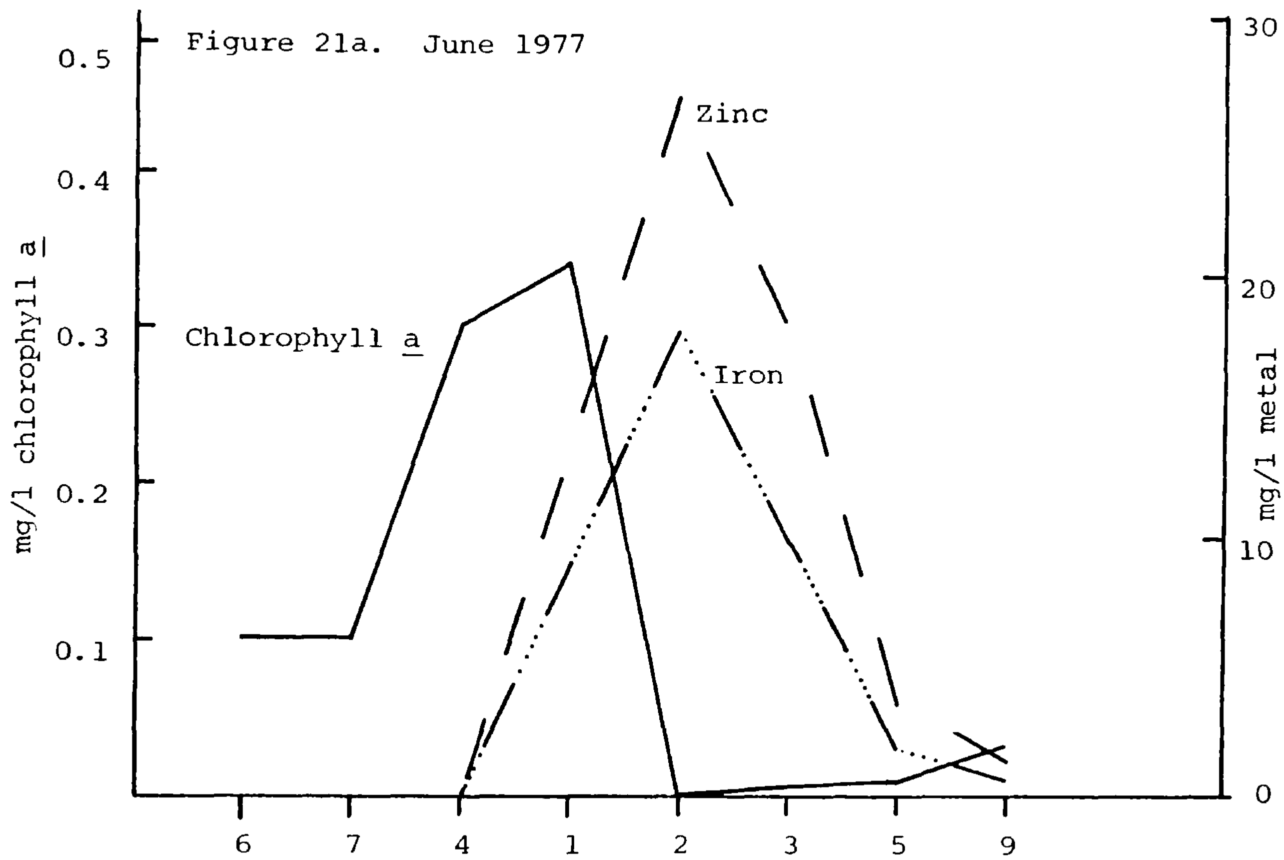
Figure 20. Chlorophyll a (mg/l) versus average dissolved zinc, copper, and cadmium and total recoverable iron (mg/l) (expanded scale for copper and cadmium concentrations).

Cadmium was only detectable at stations 2 and 3. Copper was detected during both sampling periods at station 2 but only during the June sample at station 5. It is impossible to delineate from this study their effect on primary productivity when dissolved zinc overshadows their possible influence.

Total iron and dissolved zinc concentrations were highest in June (Figure 21a). From June to July, productivity increased at stations 2, 3, 5, and 9 as metal concentrations decreased. However, there was also a considerable decrease in discharge and an increase in temperature between June and July which may have affected the primary productivity at these stations.

At station 2, the July decrease of 11 mg/l of dissolved zinc and total iron was associated with a slight increase in the chlorophyll *a* concentrations. Productivity at station 3 was not significantly affected by a decrease in zinc and iron between the two sampling periods. Although the concentrations of these two metals were reduced at stations 2 and 3 by July, it appears they were not reduced to below the toxicity threshold. Therefore, primary productivity was not significantly increased.

Between June and July, stations 5 and 9 exhibited the most dramatic increase in primary productivity of the polluted sites. However, zinc and iron concentrations were not significantly reduced during this same time period (Figures 21a and b). The lower chlorophyll *a* readings at these two stations during June may have been caused by scouring. Their subsequent increase in July may be a result of a decrease in discharge with an increase in temperature



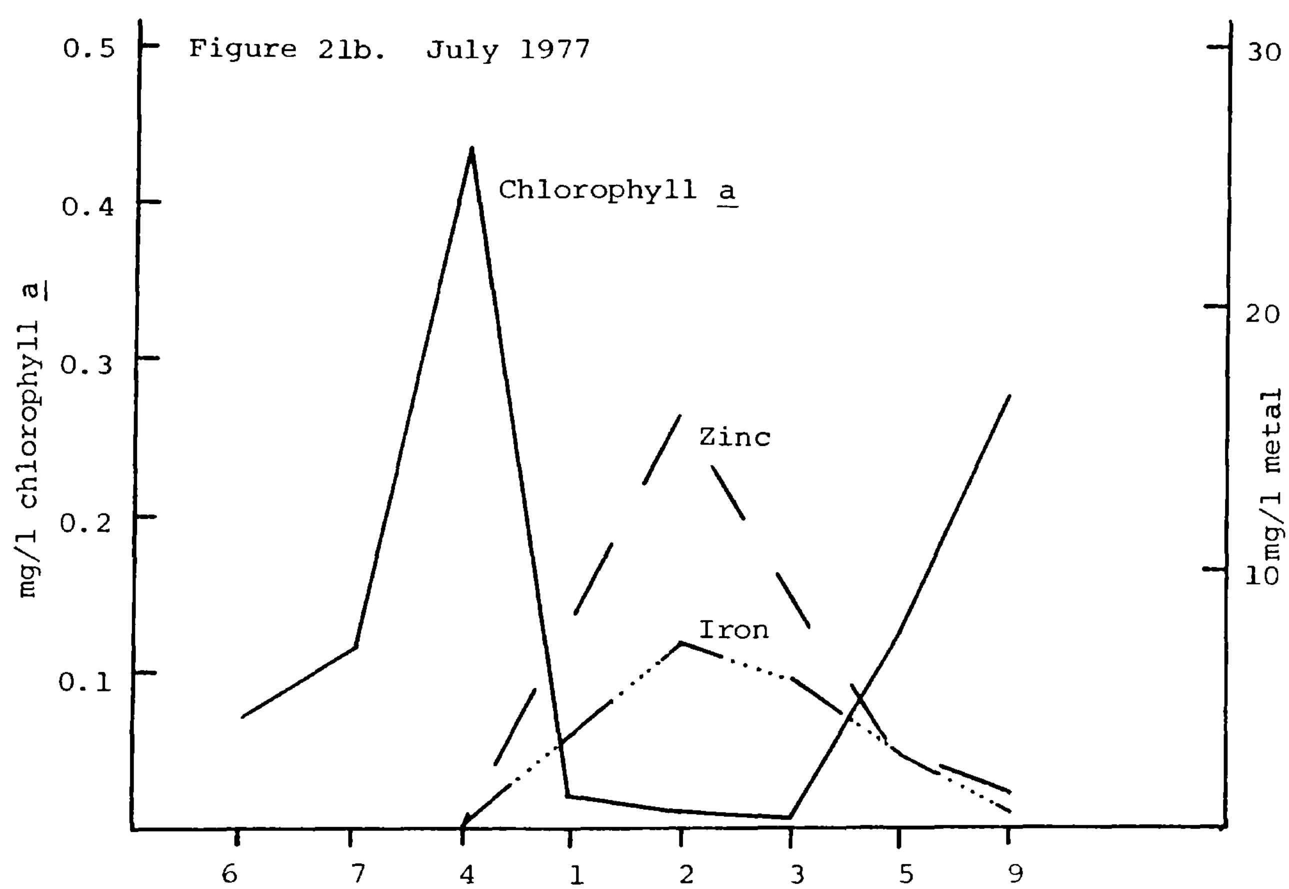


Figure 21a and b. Monthly concentrations of chlorophyll a (mg/l) versus dissolved zinc and total iron (mg/l) and radiant energy. The majority of algal species at stations 5 and 9 were filamentous and characterized by weak attachment. A higher current velocity would increase wash-out of these species. Similar species were present during June and July at station 5 and 9 but evidently in low numbers. It appears that although the filamentous algal species at stations 5 and 9 were poorly adapted to flowing water conditions, they were able to tolerate high concentrations of dissolved zinc and total iron.

The Seep in the Mike Horse Drainage

Surfacing ground water seeps appeared sporadically along the course of the Mike Horse Creek. One seep was studied throughout the sampling period. The water emerging from the seep was affected by mining (increased dissolved metals) but not by the oxidative reaction which created the iron precipitate.

Dense mats of filamentous Chlorophytes grew in the seep throughout the study period. The seeps appear as "islands" of green to the observer against the iron precipitate of the Mike Horse Creek. Throughout the study, *Ulothrix cylindricum* grew profusely in the seep. It was joined by another Chlorophyte, *Microspora quadrata*, in July. Two diatoms, *Navicula pupula var. capitata* and *Achnanthes microcephala var. microcephala* were also present. These species were classified as very resistant species (6.0 mg/l zinc and 0.6 mg/l total iron).

Throughout the study period, chlorophyll *a* concentrations were extremely high at the seep (Figure 22). These concentrations were only exceeded by the chlorophyll *a* concentrations found at station 4.

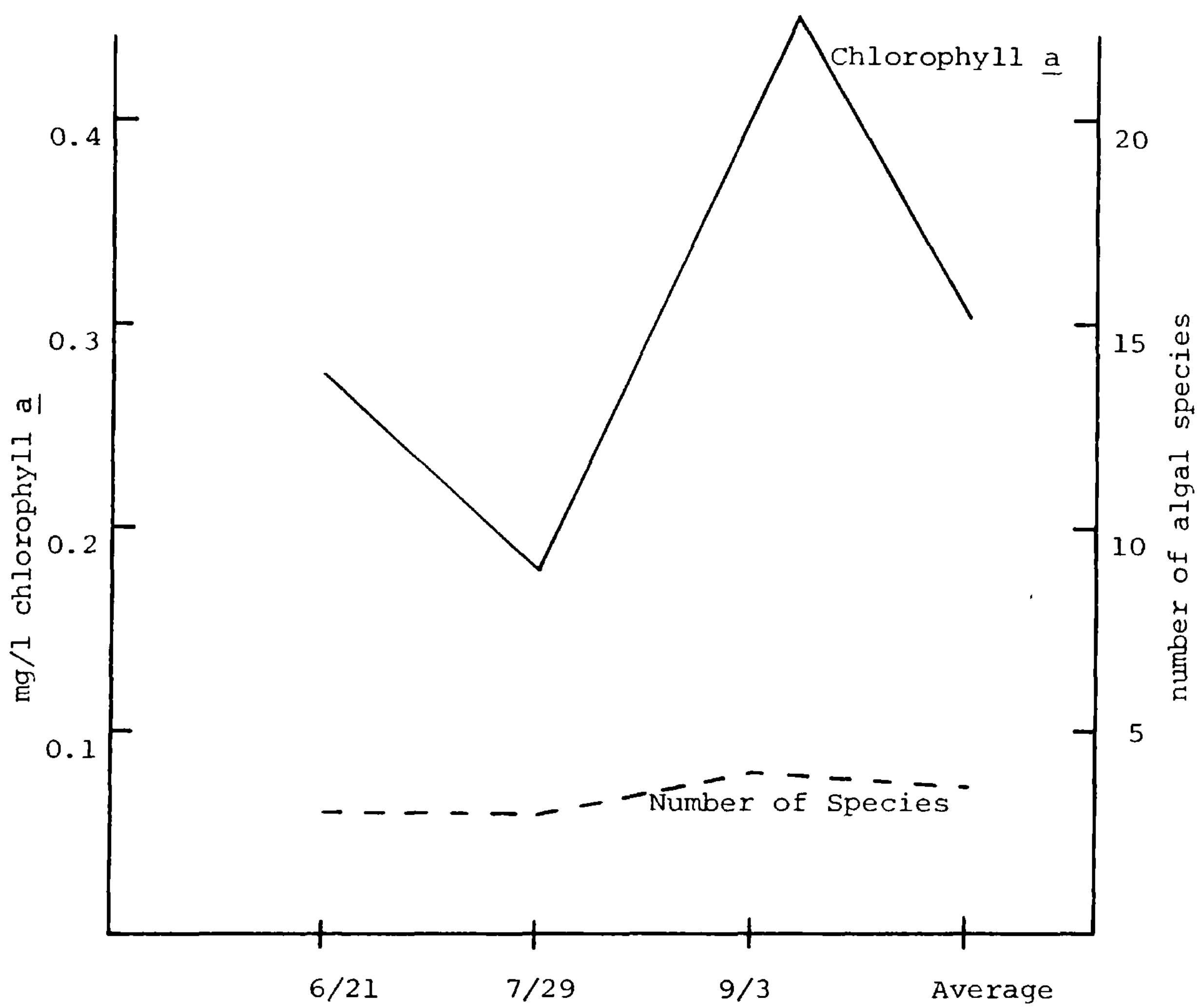


Figure 22. Monthly concentrations of chlorophyll a versus total number of algal species at the seep.

The average concentration of chlorophyll a at the seep was 0.305 mg/l. Maximum concentrations were found in September of 0.455 mg/l. The June and July readings were similar to station 1. Higher concentrations were found in June with a sag in chlorophyll a in the July sample. Primary productivity of the seep was consistently higher than stations 5 and 9 where zinc and copper concentrations were lower but ferric hydroxide precipitate was present (Figure 23).

The effect of the absence of iron precipitate combined with toxic concentrations of zinc and copper were apparent when the seep was compared with stations 5 and 9 (Figure 23). It appears the dissolved toxic metals adversely affect the diversity of the benthic algal species while the ferric hydroxide precipitate affects their densities. Higher species diversity was found at stations 5 and 9 but lower primary productivity occurred. Warner (1971) concluded the ferric hydroxide precipitate reduced the number of individuals and possibly the variety of benthic algae. He found a reduction from 19 to 13 benthic algal species at stations with an equal pH but the later being heavily coated with ferric hydroxide precipitate. Reese (1937) concluded the chief factor in determining floristic differences in areas of acid mine drainage was the deposited silt. Sediment is believed to inhibit benthic algal growth by molar action (acts as a physical barrier preventing a free exchange of gases) or by simply covering the bottom of the stream. This will shut off the light for photosynthesis to the algae and prevent attachment (Cordone and Kelley, 1961). The reduction in primary productivity adversely affects higher aquatic organisms, therefore disrupting the food chain.

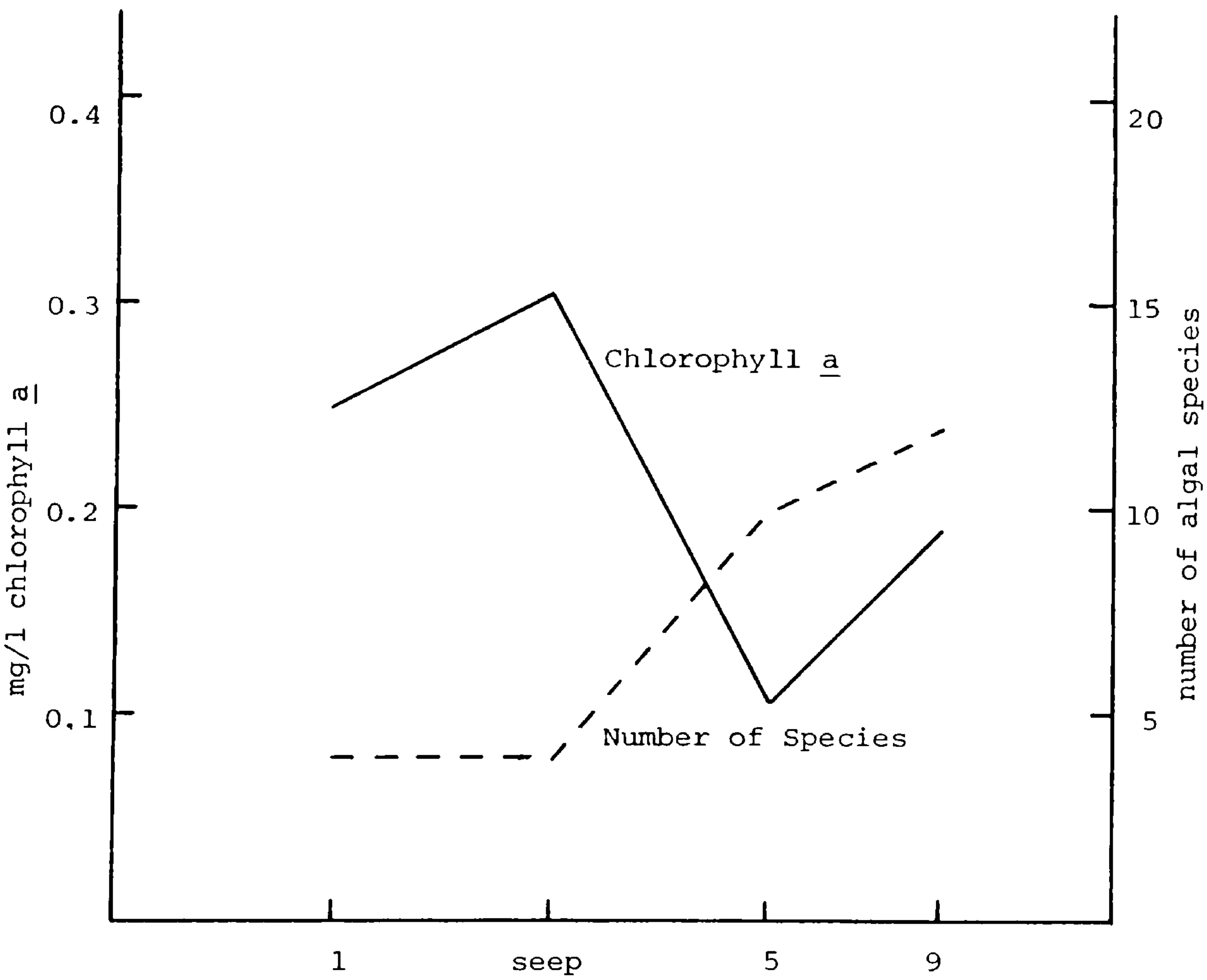


Figure 23. Chlorophll a (mg/l) versus total number of algal species at stations 1,5,9, and the seep.

Benthic Macroinvertebrates

Community Composition

During the study period, eight species of Ephemeroptera, six species of Plecoptera, five species of Trichoptera, seven species of Diptera, one species of Coleptera, and one species of Turbellaria were collected at the eight sampling stations using the Box sampler. Table 8 gives a species list and total number of individuals collected for each site.

The effect of acid mine pollution on the macroinvertebrate populations resulted in elimination or reduction of these organisms at stations 1, 2, 3, 5, and 9. A total of 551 macroinvertebrates were collected with the polluted stations (1, 2, 3, 5, and 9) contributing only 4% of the total. No specimens were collected at stations 2 and 3 where acid mine pollution was most severe. At stations 1, 5, and 9, the total numbers and percent composition were 1 (1%0, 11 (2%), and 10 (1.8%), respectively. Numbers of species were not only reduced, as found when organic pollution is the insult, but density was also severely affected. The highest total number of benthic macroinvertebrates was found at station 6 with 218 individuals or 40% of the total numbers. Twenty-three percent of the total numbers were collected at station 7 with 127 individuals. Station 4 tabulated 184 specimens during the three sampling periods or 33% of the total.

Table 9 summarizes the percent of species by order found at each station. Similar ordinal results have been found by Roback and

Table 8. Species List of Aquatic Macroinvertebrates.

	SITE							
Order Ephemeroptera	6	7	4	1	2	3	5	9
Family Heptageniidae								
Heptagenia sp.	47	45	6	0	0	0	0	0
Epeorus sp.	4	4	0	0	0	0	0	0
Rithrogena sp.	2	3	0	0	0	0	0	0
Family Ephemerellidae								
Ephemerella sp.	3	2	0	0	0	0	0	0
Ephemerella hecuba	2	0	0	0	0	0	0	0
Family Baetidae								
Baetis sp.	22	6	8	0	0	0	0	0
Family Siphlonuridae								
Ameletus sp.	3	1	4	0	0	0	0	0
Siphlonurus sp.	4	0	0	0	0	0	0	0
Order Plecoptera								
Family Perlodidae								
Arcynopteryx sp.	3	2	2	0	0	0	0	0
Family Peltoperlidae								
Peltoperla sp.	12	8	0	0	0	0	0	0
Family Perlidae								
Acroneuria theodora	10	2	0	0	0	0	0	0
Family Chloroperlidae								
Paraperla sp.	16	29	0	1	0	0	0	0
Alloperla sp.	34	14	12	0	0	0	1	0
Family Nemouridae								
Nemoura sp.	1	1	0	0	0	0	1	0
Order Trichoptera								
Family Rhyacophilidae								
Rhyacophila sp.	22	2	1	0	0	0	0	0
Family Hydropsychidae								
Hydropsyche sp.	2	2	0	0	0	0	0	0
Family Hydroptilidae	2	1	0	0	0	0	0	1
Family Leptoceridae								
Leptocella sp.	2	0	0	0	0	0	0	0

SITE

Order Trichoptera	6	7	4	1	2	3	5	9
Family Psychomyiidae								
Psychomyia sp.	5	2	0	0	0	0	0	1
Family Glossosomatidae								
Glossosoma sp.	0	3	0	0	0	0	0	0
Order Diptera								
Chironomidae								
Chironomini tribe sp. a	6	0	30	0	0	0	6	7
Chironomini tribe sp. b	2	0	48	0	0	0	3	1
Chironomini tribe sp. c	12	0	47	0	0	0	0	0
Tanytarsini sp.	0	0	2	0	0	0	0	0
Family Simulidae	0	0	1	0	0	0	0	0
Family Tipulidae	1	0	0	0	0	0	0	0
species a	0	0	3	0	0	0	0	0
species b	0	0	3	0	0	0	0	0
Order Coleoptera								
Family ?	0	0	2	0	0	0	0	0
Class Turbellaria	0	0	11	0	0	0	0	0
Total Numbers by Site	218	127	184	1	0	0	11	10

Table 9. Numbers and Percentage Composition (in parentheses) of Benthic Macroinvertebrates by Major Taxa at all stations from May through July.

Station	6	7	4	1	2	3	5	9
Taxa								
Epemeroptera	87 (36)	61 (48)	18 (10)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Plecoptera	76 (33)	56 (44)	14 (8)	1 (100)	0 (0)	0 (0)	2 (18)	0 (0)
Trichoptera	34 (17)	10 (8)	1 (71)	0 (0)	0 (0)	0 (0)	0 (0)	2 (20)
Diptera	21 (14)	0 (0)	138 (75)	0 (0)	0 (0)	0 (0)	9 (81)	8 (80)
Turbellaria	0 (0)	0 (0)	11 (6)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Other	0 (0)	0 (0)	2 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Total	218 (100)	127 (100)	184 (100)	1 (100)	0 (100)	0 (100)	11 (100)	10 (100)

Richards (1972) in waters polluted by acid mine drainage. They found Odonata, Ephemeroptera, and Plecoptera to be the most severely affected by acid mine drainage. The Trichoptera, while not completely eliminated, were also severely affected. They found the Megaloptera and Diptera to be tolerant to acid mine drainage. Parsons (1968) also found Diptera and Megaloptera to be dominant in waters polluted by acid mine drainage. Dills and Rogers (1974) collected 24 species of benthic macroinvertebrates in waters affected by acid mine drainage. The Dipteran and Coleopteran orders dominated the fauna although species from Plecoptera, Trichoptera, and Ephemeroptera were also present. The stations exposed to acid effluents in their study had a small number of individuals from these orders.

Benthic macroinvertebrates will be discussed according to monthly average trends by order and percent composition by species.

Stations unpolluted by acid mine drainage.

Station 6. During the study period, station 6 had a calculated monthly average of 73 individuals per 0.3 m^2. Highest total numbers were found in June of 121 individuals per 0.3 m^2. There was a total of 22 species of aquatic insects found during the sampling period at this station. Plecoptera and Ephemeroptera were the overall dominant orders at this station contributing 33 and 36% of the total individuals, respectively (Table 9).

In the May sample, the four orders collected at this station (Diptera, Plecoptera, Ephemeroptera, and Trichoptera) were in equal densities. Each contributed 24-26% of the total number of individuals (Figure 24).

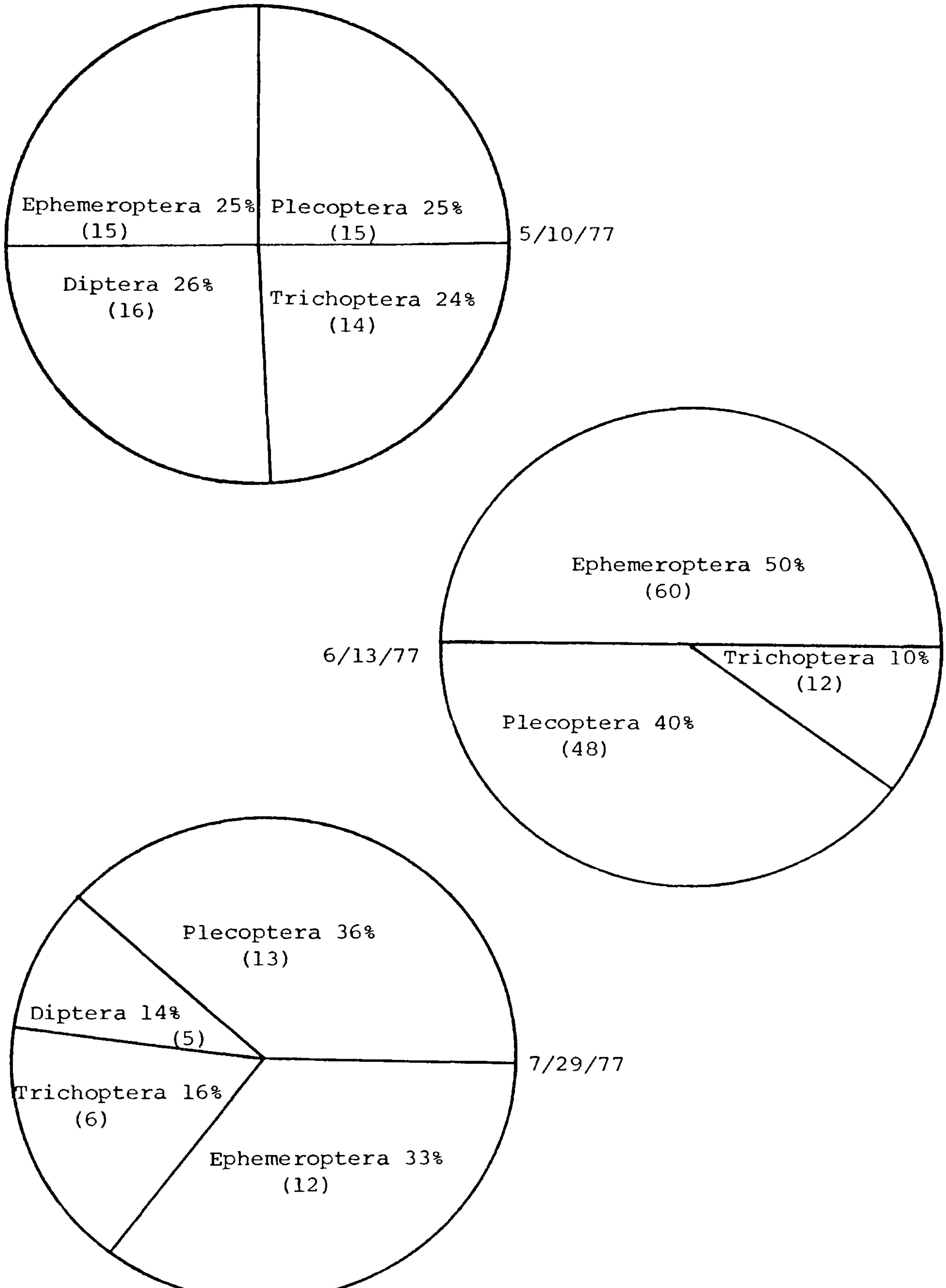


Figure 24. Percentage Composition of the Bottom Fauna by Order at Site 6. Numbers in parentheses signify actual numbers of individuals.

Fifty percent of the total number was contributed by Ephemeroptera in the June sample. This was the maximum percent contribution made by this order during the study. Total individuals were also highest during this sampling period. Individuals from Ephemeroptera decreased to 36% of the invertebrate composition in August with total numbers of 13 individuals. This was a result of the emergence of the two dominant genera in this order, *Baetis* and *Heptagenia* (Table 10).

There were eight species of Ephemeroptera collected at station 6. A species of *Heptagenia* contributed 73 and 82% of the total numbers in May and June, respectively. The emergence of this univoltine species before the late July sampling period decreased their numbers to 25% of the total number from this order. Habitat preference by the genus for moderate to rapid current with a stony bottom and clumps of aquatic moss and filamentous algae, makes the habitat of station 6 optimum for this genus (Whitton, 1975).

A species of *Baetis* contributed a maximum of 41% of the total numbers of Ephemeroptera in the July sample. Actual numbers were greater in June, however. This apparent maximum was because of a general decrease in other species from this order. *Baetis* generally occurs in riffle areas of clean or partially polluted (organic) streams during the warmer summer months (Hilsenhoff, 1975). Egglishaw (1969) reported habitat preference of *Baetis* to be most highly associated with the amount of detritus between the stones of a riffle area.

Species of the Heptagenidae family making small contributions to the Ephemeroptera order were *Epeorus sp.* and *Rithrogena sp.*

Table 10. Numbers of Individuals and Species of Macroinvertebrates at Station 6.

Species	5/10/77	6/13/77	7/29/77
Ameletus sp.	0	2	1
Baetis sp.	3	14	5
Epeorus sp.	0	2	2
Ephemerlla sp.	1	1	1
Ephemerella hecuba	0	2	0
Heptagenia sp.	11	33	3
Rithrogena sp.	0	2	0
Siphlonurus sp.	0	4	0
Acroneuria theodora	2	7	1
Acrynopteryx sp.	1	1	1
Alloperla sp.	5	26	3
Nemoura sp.	0	0	1
Paraperla sp.	5	8	3
Peltoperla sp.	2	6	4
Hydropsyche sp.	1	0	1
Hydroptilidae	0	2	0
Leptocella sp.	0	2	0
Psychomia sp.	2	3	0
Rhyacophila sp.	12	5	5
Chironomini sp. a	3	0	3
Chironomini sp. b	2	0	0
Chironomini sp. c	11	0	1
Tipulidae	0	0	1
Total by Month	62	121	36

These two species are indicative of cool, clean, rapid running streams among loose smooth stones (Hynes, 1970). They are able to maintain their position in these faster currents by a gill modification on their ventral side which forms a suction cup. Epeorus was collected in the June and July sample but Rithrogena was only collected in June at this station.

Two species of Ephemerella, E. hecuba and an unidentified species, were collected in small numbers at station 6 during the sampling period. The family Ephemerellidae, in general, has been reported as being intolerant to low oxygen levels or organic pollution (Hilsenhoff, 1975). Both of these factors were nonexistent at station 6.

A species of Ameletus of the family Siphlonuridae made small contributions at station 6 in July and August. Due to the ability of Ameletus to lay eggs that diapause, it is able to inhabit small temporary streams. Although station 6 continued to flow during the entire study period, lengths of stream above and below this station became dry when water receded into the alluvium.

Siphlonurus, another member of the Siphlonuridae family, was also found at station 6 but only during June when it contributed 7% of the Ephemeroptera's total numbers.

The order Plecoptera, displayed a similar distribution to that of Ephemeroptera. A maximum contribution was made in June of 40% with 48 individuals. Although it remained 36% of the total number in August this was due to a general decrease in all orders found at this station. The emergence of Alloperla a dominant June species, created a significant decrease in total numbers in July for this order from 48 to 12.

Six species of Plecoptera were found at station 6. Alloperla sp., mentioned above, was the dominant species in June contribution 54% to the Plecopteran total numbers. It was present in smaller numbers in May with an emergence before the July sample which decreased its numbers from 26 to 3 individuals. Paraperla, a member of the Chloroperlidae, remained in relatively stable numbers during the three sampling periods due to their emergence in the spring before sampling began.

Only one member of the Perlidae, Acroneuria theodora, was collected at station 6. This was the only large carnivorous stonefly at this station. Their numbers were higher here than at station 7. This was possibly a result of their need of suitable habitat and flow requirements to complete their two year life cycle. Although discharge decreased at both stations during the sampling period, station 6 continued to have a steady flow. Station 7 became an isolated pool by September. Small amounts of water surfaced from the stream bed above this station which prevented its' complete drying out. Two years of A. theodora were collected during the June sample at station 6. Due to their emergence occurring before the July sample, only the smaller nymphs were collected.

A species of Nemoura was collected only during the late July sample. The two previous sampling times were after adults had emerged but prior to nymphal hatch.

Peltoperla sp. was collected during all three sampling periods with their greatest numbers in June. Nymphs were collected in all stages of their three year life cycle.

Diptera contributed a monthly average of 14% to the total numbers at station 6. Its numbers were at a maximum in the May sample where it contributed 26% of the total number of individuals collected. At this collection, 3 members of the Chironomini tribe (Species a, b, and c) contributed the entire 16 individuals found. This order was unrepresented in the June sample because of the emergence of the Chironomini species. The July contribution from the Diptera was 14% of the total numbers collected. Five individuals from two species of Chironomini and one individual from the Tipulidae family were collected.

The Trichopteran order contributed a monthly average of 11 individuals to the total number at this station or 17%. A maximum contribution of 24% was displayed in the May sample. This high percentage was biased, however, due to a number of Rhyacophila sp. in a clump of Hygrohyphum dialtatum, an aquatic moss. The clump was detached from the substrate and floated into the sampling net. This species of Rhyacophila contributed 80% of the Trichoptera during the May sampling period. Rhyacophila a univoltine species, is well adapted to riffle areas due to a large strong anal proleg and widely spaced thorasic legs. These two adaptations enable it to maintain a strong hold on moss or filamentous algae in a swift current. Although discharge decreased at this station during the sampling period, velocity maintained a consistent level. Rhyacophila was the dominant species of this order during the three sampling periods.

Twelve Trichopteran larvae or 10% of the total number of individuals were collected in the June sample. Percent of individuals increased to 16% during the July sample even though the number of individuals actually decreased to 6. Other species of Trichoptera found at this station were in relatively low numbers. Hydropsyche sp. contributed one individual in May and July but were not present in the June sample. Both specimens were of equal size so it appears that Hydropsyche has a staggered emergence over the summer. Hydropsyche is a widespread genus, omnivorous and has been collected in streams that are not severely organically polluted (Hilsenhoff, 1975). They are net spinners with specific current requirements of not less than 15 cm/sec (Macan, 1974). This velocity occurred throughout the study at this station. A species of Psychomia contributed two individuals in May or 13% and 25% of the total individuals in June. No individuals from this genus were found in the July sample possibly due to its emergence before this sample. Psychomia is a widespread genus but is characteristic of cold running waters in stones embedded in the bottom or in filamentous algae on stones (Percival and Whitehead, 1929).

Tow other species of Trichoptera, which contributed small numbers of individuals, were a species of Leptocella and Hydroptilidae in July. The species of Hydroptilidae was found in its free living stage and could not be identified to genus.

Station 7. Station 7 not only had a smaller total number of macroinvertebrates (127 individuals) than station 6 but also had only 17 species represented. This reduction in numbers as well as species was a result of fewer available habitats (no aquatic moss or small pools, only one undercut bank) and the uncertainty of flowing water by the end of July.

Station 7 had an average of 42 individuals per 0.3 m^2 with the maximum number in May of 55 per 0.3 m^2. Total numbers declined in July largely due to the emergence of the dominant species at this station, _Paraperla_.

With only three orders represented at this station (Trichoptera, Ephemeroptera, and Plecoptera), Ephemeroptera and Plecoptera shared the overall ordinal dominance, contributing 48 and 44% of the total numbers, respectively (Table 11).

Ephemeroptera was dominant in the June and July sample at station 7 because of a significant decrease in the Plecopteran total numbers (Figure 25). The six species of Ephemeroptera present at this station were all found at station 6 though numbers were reduced at the former. A species of _Heptagenia_ accounted for 94% of the Ephemeroptera in May and 76% in June. Its decrease in percentage in June was not due to a reduction in its total numbers but to an increase in other species of Ephemeroptera (Table 11). The emergence of this genus before the July sample caused the numbers of individuals as well as the percent composition to decrease.

A species of _Ameletus_, _Epeorus_, and _Ephemerella_ were found only in the July sample. This may have been caused by a migration from

Table 11. Numbers of Individuals and Species of Macroinvertebrates at Station 7.

Site 7	5/10/77	6/13/77	7/29/77
Ameletus sp.	0	0	1
Baetis sp.	1	5	0
Epeorus sp.	0	0	4
Ephemerella sp.	0	0	2
Heptagenia sp.	16	22	7
Rithrogena sp.	0	2	1
Acroneuria theodora	1	1	0
Arcynopteryx sp.	0	0	2
Alloperla sp.	5	6	3
Nemoura sp.	0	0	1
Paraperla sp.	22	4	3
Peltoperla sp.	6	2	0
Glossoma sp.	0	3	0
Hydropsyche sp.	0	1	1
Hydroptila sp.	1	0	0
Psychomia sp.	1	0	1
Rhyacophila sp.	2	0	0
	55	46	26

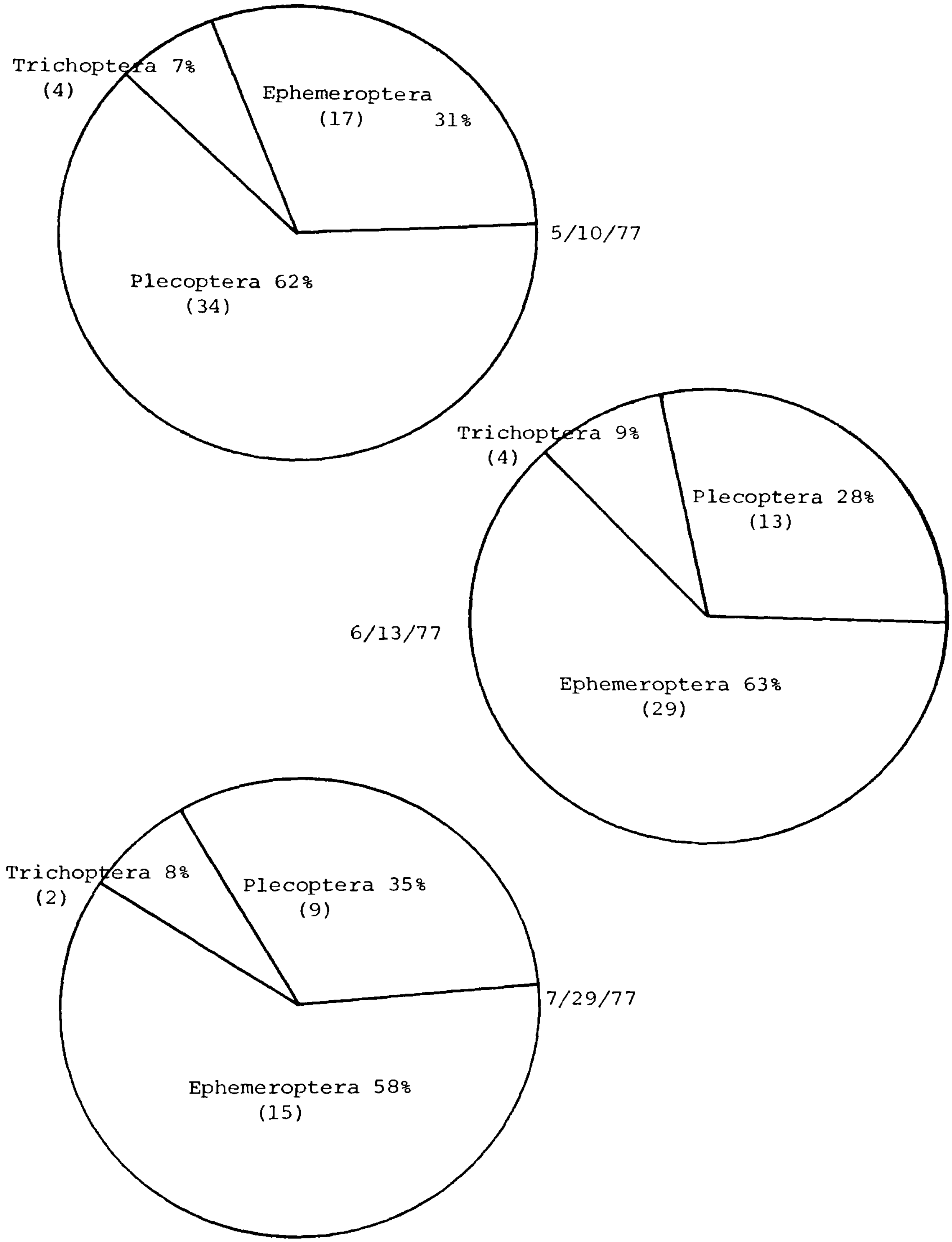


Figure 25. Percentage Compositon of the Bottom Fauna by Order at Site 7. Numbers in parentheses signify actual numbers of individuals.

areas of the stream above and below this station whose waters had receded into the streambed. *Baetis* was collected in greatest numbers in the June sample where it contributed 17% of the Ephemeropteran individuals. Its absence in the July sample probably was caused by its emergence before the sample.

Plecoptera was the dominate order only during the May sample, contributing 62% of the total invertebrates found. Contributions by this order in June and July were 28 and 35%, respectively. The increase in percent composition by Plecoptera in July was not a result of an increase in individuals but a general decrease in Ephemeroptera and Trichoptera at this station.

Six species of Plecoptera were found at station 7, all of which exhibited higher numbers at station 6. *Paraperla sp.* was the only substantial contributor in May from this order, accounting for 65% of the Plecopteran individuals. The late spring emergence of this genus led to a decrease in percent composition to 31% by June and 33% by July. Individuals of a species of *Alloperla* remained relatively stable during the three sampling periods with a slight decrease in the July collection. *Nemoura* and *Arcynopteryx sp.* exhibited similar behavior as did the three species of Ephemeroptera which were only found at this station in the late July sample. *Nemoura*, however, was collected only in July at all the stations where it was recorded. This was probably due to the early emergence of this genus in late spring and early summer causing no nymphs to be collected in the May and June samples. By July, the nymphs had hatched and were collected in low numbers in the sampling areas.

Acroneuria theodora was present during the two earlier samples but was not found in the late July collection. A possible explanation for this pattern was discussed under station 6. Peltoperla sp. was absent from the July sample also. This absence may be a result of the alteration of habitat caused by the decrease in discharge at station 7 in July. Peltoperla sp. has a three year life cycle and such changes may have caused emmigration from this area by this species.

Trichopteran species contributed only 8% of the total numbers of individuals collected at station 7. Monthly contributions varied little and no species were collected in large numbers.

Four species of Trichoptera were collected at station 7. Glossoma sp. had a maximum number of three individuals in the June sample. No individuals from this genus were collected in the May or July samples. The May absence may have occurred due to emergence of adults. Hatching of the mymphs would have caused the increase in the population in June. The reason for the absence of this species in July is unknown. Its habitat requirements are clean, clear streams free from organic pollution in moderate to fast current (Hynes, 1970). It is a herbivore, scrapping algae, diatoms, and detritus off the rocks in riffle areas (Ward and Whipple, 1959). Two individuals from the Hydropsyche genus were found in June and July. It appears this species has a staggered emergence over the summer since both of these specimens were of the same size one month apart. Other species contributing small numbers to the Trichopteran individuals were one species of Hydroptilidae in May, two individuals from Psychomia in May and July, and two individuals from the Rhyacophila genus in May. Populations of Rhyacophila were not as great as those found at station 6. This may have been due to the lack of aquatic moss at station 7 which Rhyacophila is known to prefer.

Station 4. The benthic macroinvertebrates responded adversely to the impoundment 500 feet above this station by a decrease in overall diversity with an increase in density of species in the Dipteran order. Seventy-five percent of the 184 total individuals found at this station were from the Dipteran order (Table 9). The Plecoptera, Ephemeroptera, and Trichoptera contributed only 8, 10 and >1% of the total individuals, respectively. Two taxa not found at any other station, ine insect order Coleoptera and the invertebrate Turbellaria, were collected in small populations at this station.

Site 4 had a monthly average of 61 individuals per 0.3 m^2. The maximum density of 128 individuals per 0.3 m^2 was collected in August. This maximum in individuals occurred as a consequence of a substantial increase in the Dipteran individuals, not because of an increase in all orders.

Various chemical and physical changes occur in waters downstream from an impoundment which, in turn, affect the macrobenthos of that water. Fluctuations in water temperature are reduced causing cooler temperatures during the summer, siltation of the stream is increased due to control of the water at runoff which prevents scouring, and the nutrient and total dissolved solids are increased which causes an increase in benthic algal populations and a subsequent decrease in nocturnal oxygen levels due to an increase in algal respiration

(Hilsenhoff, 1971). These changes contribute to adverse conditions for the diversity and density of the macrobenthic populations. Ward (1974) concluded that the change in the temperature regime was responsible for the low diversity by failing to stimulate various developmental stages of the insects life cycle or by seasonally altering developmental patterns. Ward found the order with the greatest ability to withsatnd these conditions below the reservoir were the Dipterans. Hilsenhoff (1971) discovered similar results but felt the changes in the macroinvertebrates were because of the increase in nutrient levels and siltation.

Because of the objectives of this study, it is impossible to determine what factors at station 4 have the greatest adverse effect on the macroinvertebrate population due to inadequate sampling of dissolved oxygen (not sampled at night) or temperature. Evidence of higher nutrient levels was apparent. Specific conductivity was higher at this station than the other unpolluted sites and the highest levels of primary productivity were consistently found at this site. This was also the only site where macrophytes were growing in the stream during the entire study period. Although dissolved oxygen was above 7.0 ppm when sampled, samples were not taken at night when the effect would be greatest due to algal respiration. Temperature, when sampled, was significantly lower here than station 3. This difference ranged from 1.5-11.5°C lower at station 4 when readings between these two stations (50 yards apart) were taken within five minutes of each other. Based on this evidence, it appears higher nutrient levels and increased temperatures created by the impoundment above station 4, may be the cause of the alterations in the macroinvertebrate community at this station. The increase in nutrients caused a subsequent increase in benthic algae. These dense mats may create a depletion in the nocturnal oxygen levels due to an increase in respiration from these plants. As mentioned previously, colder temperatures may not stimulate various developmental stages in the macroinvertebrates. There is need for further investigation of this situation before these tentative conclusions can be verified.

Diptera was the dominant order at this station. They contributed 62%, 61%, and 82% of the total individuals in May, June, and July, respectively and averaged 75% of the total individuals each month. The substantial increase to 82% in July was the result of three species in the Chironomini tribe (Table 12). These three species (a, b, and c) contributed 93% of the individuals from this order in July. Hilsenhoff (1971) and Hynes and Spence (1971) reported an increase in *Chironomus* in riffles below hypolimnion impoundments. Hynes and Spence (1971) concluded this increase was a result of the greater availability of detritus. Percival and Whitehead (1929) found members of this tribe to increase with an increase of filamentous algae on stones. By June, much of the stream bed at station 4 was thickly covered with *Ulothrix cylindricum*, *Microspora quadrata*, *Spirogyra porticalis*, and *Schizomeris Leibleinii*. This dramatic increase of Chironomini in the July sample was probably due to a June emergence of adults with the midges hatching in July.

Table 12. Numbers of Individuals and Species of Macroinvertebrates at Station 4.

Species	5/10/77	6/13/77	7/29/77
Ameletus sp.	0	1	3
Baetis sp.	5	2	1
Heptagenia sp.	0	5	1
Alloperla sp.	1	0	11
Arcynopteryx sp.	0	1	1
Rhyacophila sp.	0	1	0
Chironomini sp. a	3	8	19
Chironomini sp. b	6	7	35
Chironomini sp. c	3	8	36
Simulidae	0	0	1
Tipulidae sp. a	1	1	1
Tipulidae sp. b	0	0	3
Tanytarsini	0	0	2
Coleoptera	1	0	1
Turbellaria	2	5	4
Total by Month	22	39	123

Although only one individual from the Simulidae family was collected from the Box sampler, 12 were counted on one of the glass plates at this station in July. The occurrence of this family at this station is not surprising because of the channelization that occurred during the dam rebuilding in 1975. Hynes (1970) reported that Simulium seemed to be encouraged by canalization of small streams because of its need for swift, fairly laminar flow over a stable substratum. Other contributing members of the Dipteran order were two species of Tipulidae found during all sampling periods (Table 12). Two individuals from the Tanytarsini tribe were found in the late July sample.

Ephemeroptera contributed a monthly average of 10% of the total numbers at station 4. Although monthly percent compositions did differ, number of individuals remained fairly consistent (Figure 26). These individuals were from three genera, Baetis, Ameletus, and Heptagenia. Baetis contributed maximum individuals in May with declining numbers in the latter samples due to emergence. This pattern was different from Baetis emergence at stations 6 and 7 which occurred after the June sample. Temperature alterations because of the dam may have caused this early emergence at this site. Spence and Hynes (1971) found an increase in Baetis below an impoundment due to an increase in foods and attached filamentous algae which provided microhabitats for nymphs. These dense filaments also hold more detritus than riffle area rubble and gravel. Heptagenia and Ameletus were collected only in the last two samples contributing a small number of individuals (Table 12).

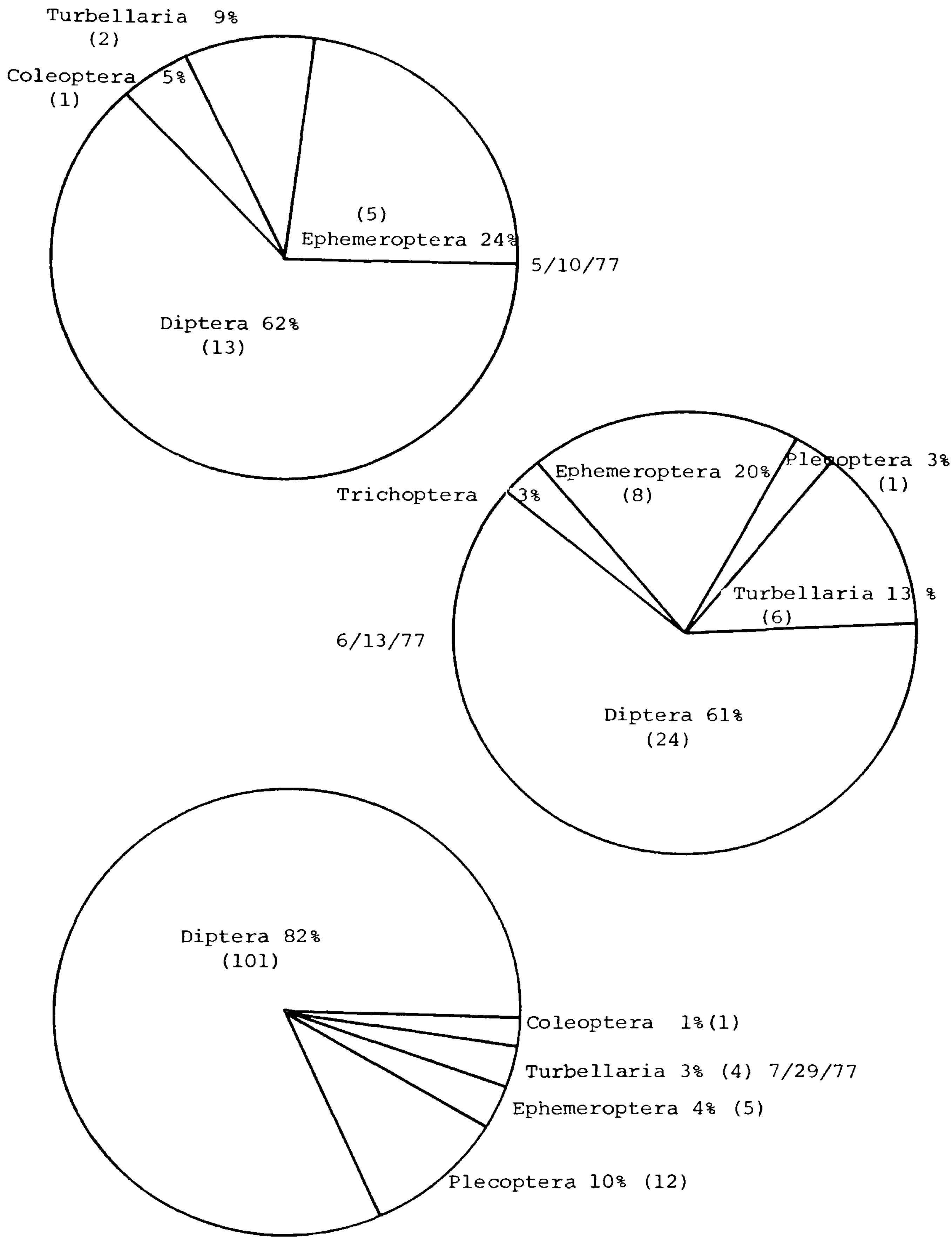


Figure 26. Percentage of the Bottom Fauna by Order at Site 4. Numbers in parentheses signify actual numbers of individuals.

Only two species from the Plecopteran order were collected at station 4, Alloperla sp. and Arcynopteryx sp. This order was completely absent from the May sample, contributed one individual in the June sample, and increased to 10% of the total numbers found in the July sample due to a hatch of Alloperla nymphs. Though there is no evidence to substantiate this absence, Spence and Hynes (1971) suggested the night time oxygen demand of the dense algal mats eliminates the oxygen sensitive Plecoptera from areas below hypolimnion impoundments.

Trichoptera was completely absent from station 4 except for one individual of the genus Rhyacophila found in the June sample. Hilsenhoff (1971), Spence and Hynes (1971), and Ward (1974) found a reduction in Trichopteran diversity below dams. Ward, however, reported highest numbers of individuals of Rhyacophila at the first station below the dam on the South Platte River in Colorado. Various authors have recorded an increase in filter feeding Trichoptera (which Rhyacophila is not) density below dams possibly resulting from contributions of lentic plankton (Briggs, 1948; Spence and Hynes, 1971; and Ward, 1974).

A species of Turbellaria was consistently collected at station 4, contributing an average of 6% of the total individuals found. One nymph in May and one adult in July of Coleoptera were also collected.

Polluted stations. The benthic macroinvertebrate population was essentially nonexistent at stations 1, 5, and 9, and no macroinvertebrates occurred at stations 2 and 3. The density of the individuals as well as the diversity were both severely affected by the pollution.

A total of 22 individuals from the Dipteran, Trichopteran, and Plecopteran orders were collected at stations 1, 5, and 9 during the three sampling periods.

Station 1. A 100% contribution by Plecoptera of one individual was collected at station 1 (Table 13). This individual was found in May and no insects were found at this station after this first sampling period. Unfortunately, no heavy metal analysis was reported at this station but there was no evidence of ferric hydroxide precipitate during the study period. This does not rule out toxic concentrations of zinc or copper or some other metal, however. Evidence of this conclusion exists when benthic algal species list from site 1 are compared with those of the seep. Identical species were collected at these sites during the sampling period. The seep was analyzed for heavy metals in July and toxic concentrations of dissolved zinc and copper were found.

Station 5. The Diptera was the dominant order at station 5, contributing 81% of the 11 individuals collected (Table 9). Two species of Chironomini (a and b), from the Dipteran order, contributed 100% of the individuals collected in the May and June samples of one and three individuals, respectively (Figure 27). These four individuals collected during these two sampling periods may have been caused by drift from station 4. An increase in these two species at station 5 occurred in the July sample, contributing 71% of the individuals collected. Four individuals of species a and one specimen

Table 13. Numbers of Individuals and Species of Macroinvertebrates at Stations 1, 5 and 9.

Species	5/10/77	6/13/77	7/29/77
Station 1			
Paraperla	1	0	0
	—	—	—
Total by Month	1	0	0
Station 5			
Alloperla sp.	0	0	1
Nemoura sp.	0	0	1
Chironomini sp. a	1	1	4
Chironomini sp. b	0	2	1
	—	—	—
Total by Month	1	3	7
Station 9			
Psychomyia sp.	0	0	1
Hydroptilidae	0	0	1
Chironomini sp. a	0	7	0
Chironomini sp. b	0	0	1
	—	—	—
Total by Month	0	7	3

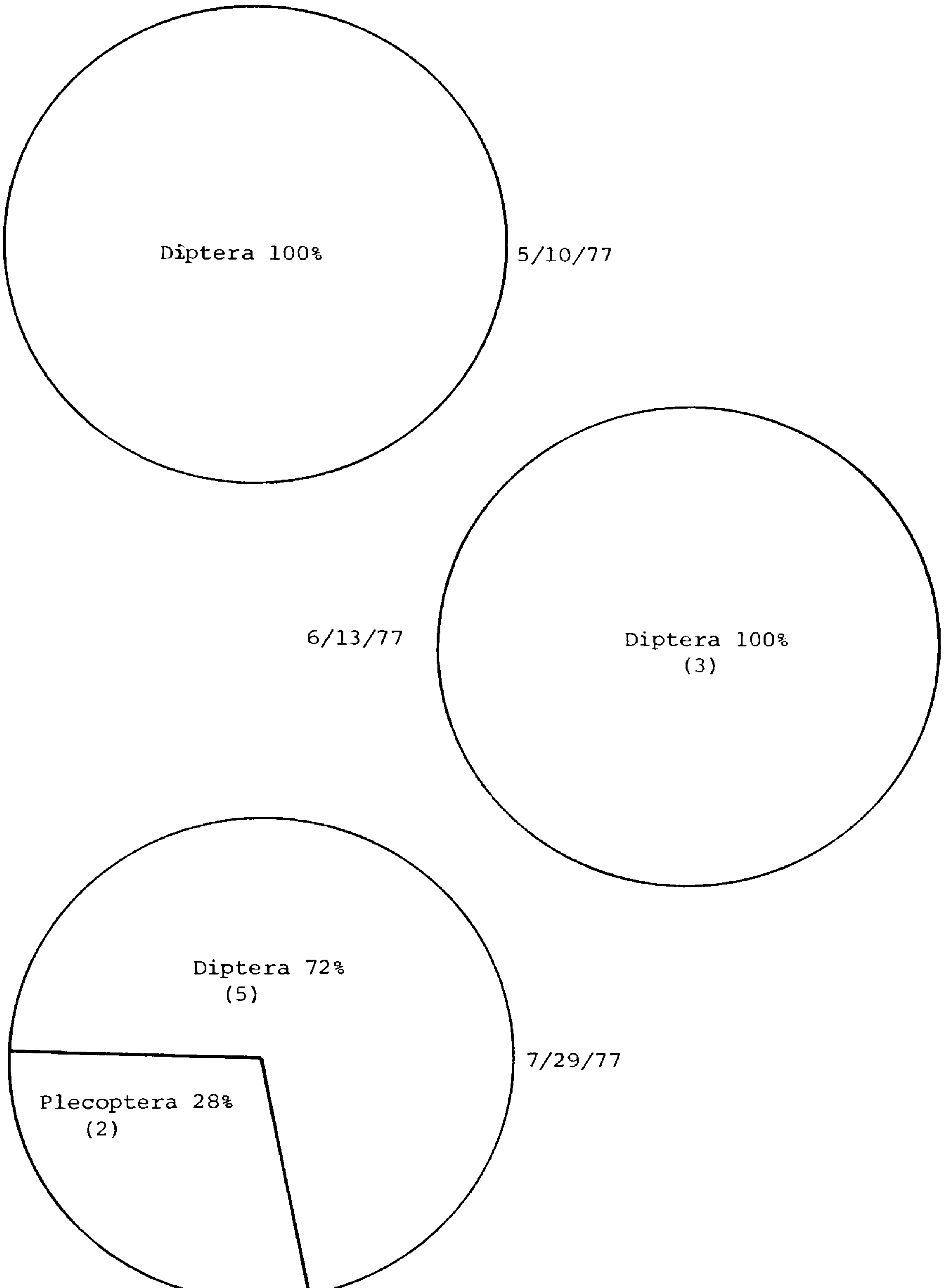


Figure 27. Percentage Composition of the Bottom Fauna by Order at Site 5. Numbers in parentheses signify actual numbers of individuals.

of species b were found. There was also a significant increase of these two species at station 4 (Table 12). Again, drift may have caused this increase.

Members of the family Chironomidae have been reported as being the dominant order in waters polluted by acid mine drainage by many authors (Dills and Rogers, 1974; Nichlos and Bulow, 1973; Koryak, et al., 1972; Roback and Richards, 1969; high density but not dominant, Parsons; 1968; and Harrison, 1958). These authors reported Chironomidae in waters with a low pH (3.5-5.1). Neither copper, zinc, or iron were analyzed from these waters except in the study by Parsons. Koryak et al. (1972) concluded Chironomus predominance in acid mine waters may be due to the hemoglobin they possess, enabling them to obtain and transport oxygen under low oxygen tension. The hemoglobin may also provide a buffering system capable of minimizing the deleterious effects of los pH or adverse ionic balances. Chironomus has also been found to be dominant in waters which are high in sediment (Hynes, 1963 and Gammon, 1970). Gammon found Chironomiae preferred fine sand and silt or rubble covered with thick mats of filamentous algae.

In the late July sample, two species of Plecoptera were collected at station 5, contributing 25% of the eight individuals found. Drift from station 4 could be hypothesized as the cause for these species occurrences, since only one individual from each species was collected. Only one of the species, Alloperla sp., was found at station 4, however. The other species, Nemoura, was not present at station 4 but occurred during the same sampling period at stations 6 and 7.

This concurs with reported hatching time of August to October for this genus. Vandenberg (1974) and Dambach and Olive (1969) also found an unidentified species of Nemoura in waters polluted by acid mine drainage. Dambach and Olive found Nemoura in densities of 55 individuals per m^2. Vandenberg reported a species of Nemoura when zinc and copper concentrations were 1.75 mg/l and 0.29 mg/l, respectively and pH above 6.0. He also found a species of Alloperla in waters of 1.69 mg/l zinc and 0.21 mg/l copper.

Zinc concentrations were higher at station 5 in this study but copper concentrations were lower than that of Vandenberg's study. The increase in species at station 5 during the July sampling period may have been caused by the reduction of dissolved copper from 0.01 mg/l in June to below the detectable limit by the July sample. Zinc and copper are known to be highly synergistic. Lloyd (1969), during experiments with zinc and copper on fish populations, discovered that minnows could survive concentrations of 8.0 mg/l zinc or 0.2 mg/l copper but died in waters with concentrations of 1 mg/l zinc and 0.025 mg/l copper. Zinc and copper concentrations at station 5 were, respectively, 3.5 mg/l and 0.01 mg/l in June and 3.0 mg/l and <0.01 mg/l in July.

Station 9. There was no downstream increase in benthic macroinvertebrates at station 9 although different species were present. Diptera, again, dominated the macroinvertebrates at this station. Eighty percent of the total of 10 individuals collected at this station were contributed by this order.

No insects were collected during the May sampling period. Populations increased to seven individuals in the June sample (Figure 28). These seven individuals were from one species of the Chironomini tribe (species a). This species was also found during the June sample at station 5 but in lesser numbers (Table 13). No members of this species were found at station 7 during the June sample. With no substantial upstream population of this species from which drift could occur, it is possible this species was a resident of station 9 during its aquatic life cycle. This species was reduced to zero by the July sampling, probably due to emergence. Three different species were collected at this station during the July sample, each contributing one individual. One individual from the Chironomini tribe, species b, was collected. Two species of Trichoptera were collected, a *Psychomia sp.* and a member of the Hydroptilidae family. Due to their low populations, their presence at station 9 is of little significance. If these species were actually inhabiting these waters, higher densities of individuals would be expected. No reports of these species occurring in acid mine drainage streams have been found.

Community Diversity

Of the eight stations sampled for benthic macroinvertebrates, diversity indices could only be calculated for five of the stations. At stations 2 and 3, as mentioned previously, no benthic macroinvertebrates were collected during sampling. At station 1, only one individual was collected during the entire sampling period. The

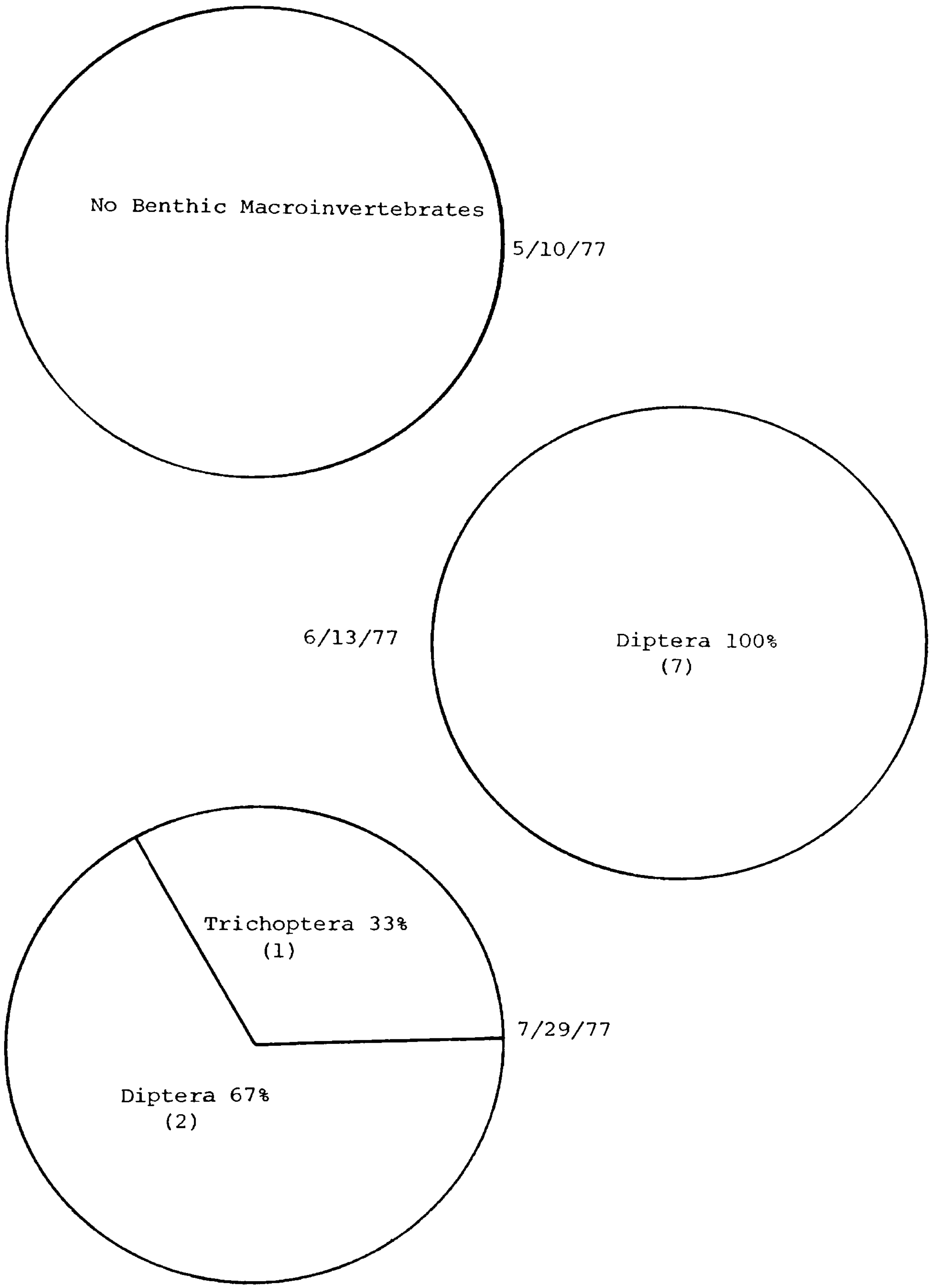


Figure 28. Percentage Composition of the Bottom Fauna by Order at Site 9. Numbers in parentheses signify actual numbers of individuals.

Shannon-Weaver diversity index (Shannon and Weaver, 1963) was used on the remaining five stations to relate abundance of individuals with distribution at each site. Table 14 presents the diversity indices and the total number of individuals for each station during the three sampling periods.

Unpolluted stations. Station 6's diversity was 2.2769 in May and increased to 2.6103 in July. The mean diversity for this station was 2.4047, which was the highest mean for all the stations.

Station 7, with a mean diversity of 1.8154, had an initial diversity of 1.6257 in May and steadily increased to a maximum of 2.1602 in July.

Station 4 displayed a maximum diversity of 2.0535 in June. Lower diversities were calculated for May of 1.6129 and July of 1.8444. The mean diversity for this station was 1.8369.

Polluted stations. Diversity indices at stations 5 and 9 were considerably lower than those of the unpolluted stations. A gradual increase in diversity occurred at station 5 during the study period. Diversity was 0 in May, increased to .6401 in June, and showed a maximum of 1.1457 in July. There were seven individuals present in four different species in the July sample at station 5.

Station 9 displayed similar results to that of station 5 with respect to species diversity. No diversity could be calculated in May due to no invertebrates collected in the sampling or June because of only one species being present. In July, diversity

Table 14. Diversity Indices and Total Numbers of the Benthic Macroinvertebrates (.3 m^2) for the Headwaters of the Blackfoot River, May through July, 1977. (Sites excluded with no diversity or individuals.)

Date	SITE 6	SITE 7	SITE 4	SITE 5	SITE 9
Diversity Indices					
5/10/77	2.2769	1.6257	1.6129	0.00	0.00
6/13/77	2.3268	1.6604	2.0535	0.6401	0.00
7/29/77	2.6103	2.1602	1.8444	1.1457	1.1034
Average	2.4047	1.8154	1.8369	0.5953	0.3678
Total Numbers					
5/10/77	62	55	21	1	0
6/13/77	120	46	39	3	7
7/29/77	36	26	123	7	3
Total	218	127	184	11	10

increased to 1.1034, caused by three individuals from three different species.

Total Numbers of Individuals vs. Species Diversity

Total numbers of individuals and diversity indices were compared at each site to determine the maturity and stability of the ecosystem being sampled. These comparisons are graphically displayed in Figure 29a through f.

Unpolluted stations. At station 6, diversity indices were consistently high while total population fluctuated throughout the study period (Figure 29a). This pattern illustrates a high resident community with its population fluctuating due to hatching of eggs and emergence of adults. A high diversity illustrates an equal distribution of species in the community. Most authorities conclude that an equality of species is reached over a long period of time in highly stable environments. From a comparison of diversity with total numbers, it appears that station 6 was the most mature ecosystem of the five stations.

Station 7 had a fairly high, consistent diversity but with a much lower number of total individuals than station 6 throughout the study period (Figure 29b). Diversity increased at this station when there was a decrease in total numbers, possible because of a limited number of habitats. It appears this station had a variety of limited microhabitats causing the carrying capacity to be fairly low.

Figure 29a-f. Total number of benthic macroinvertebrates versus species diversity for each station in May, June, and July, 1977.

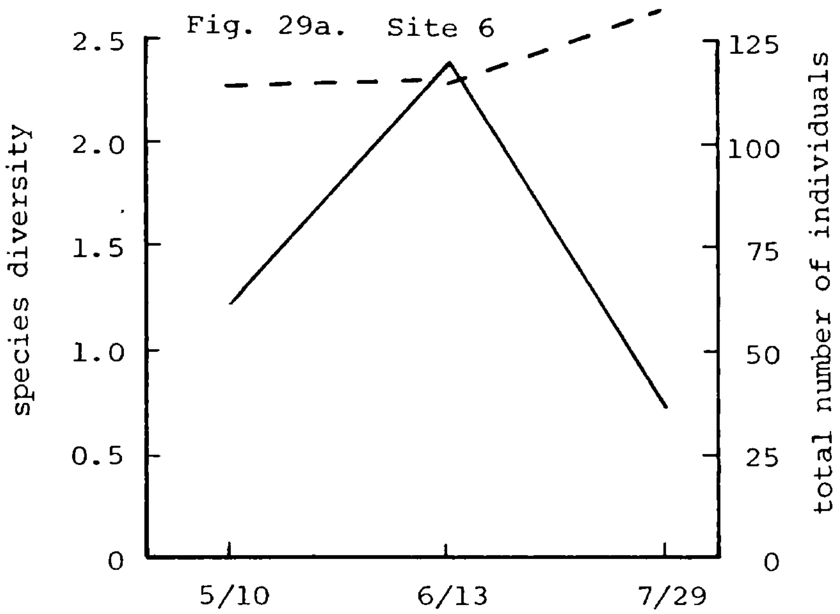


Fig. 29a. Site 6

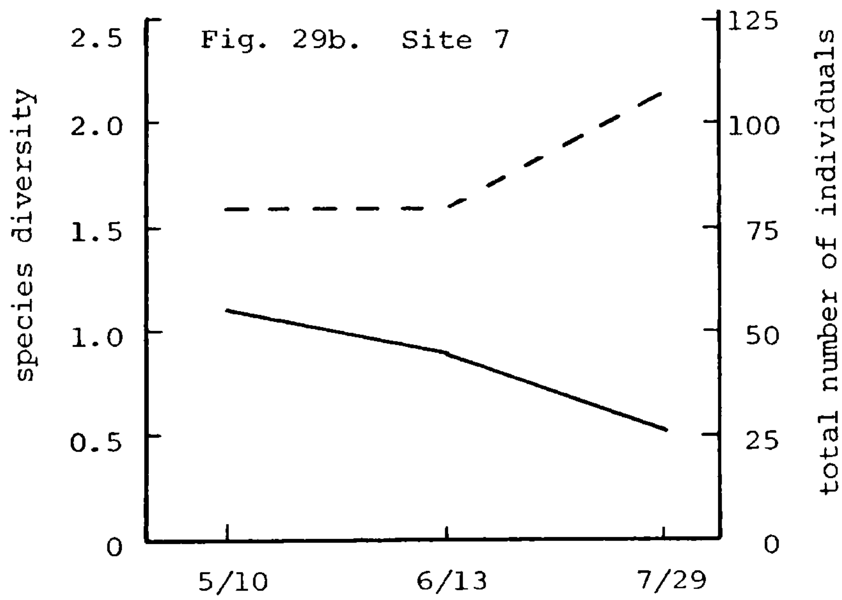


Fig. 29b. Site 7

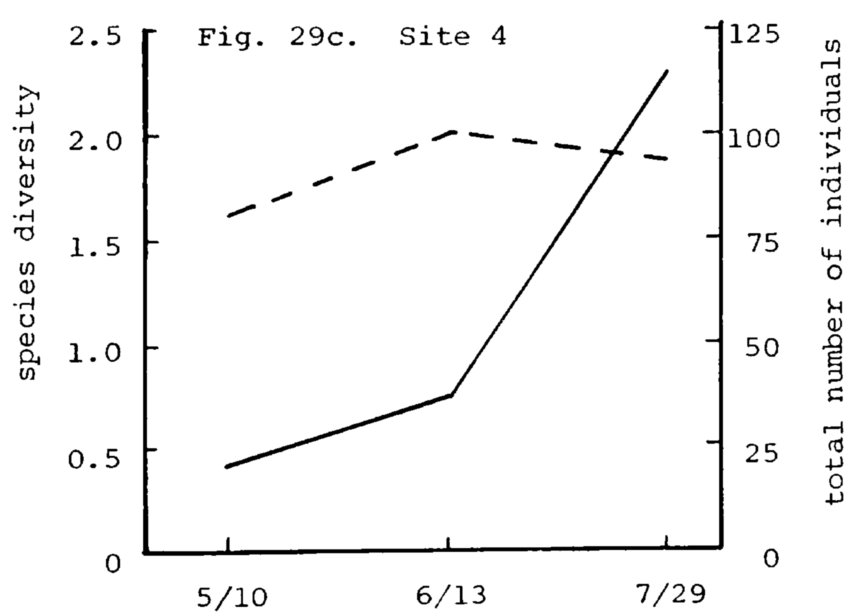


Fig. 29c. Site 4

total number of individuals ————

species diversity – – – – –

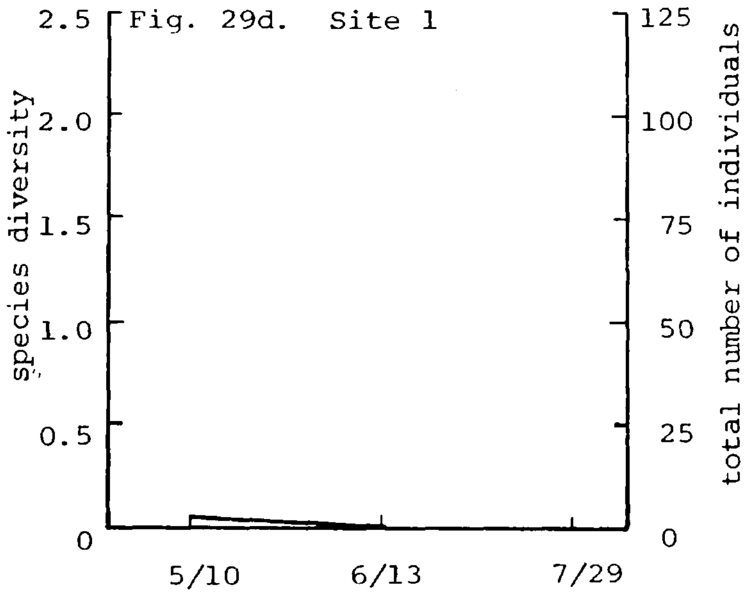


Fig. 29d. Site 1

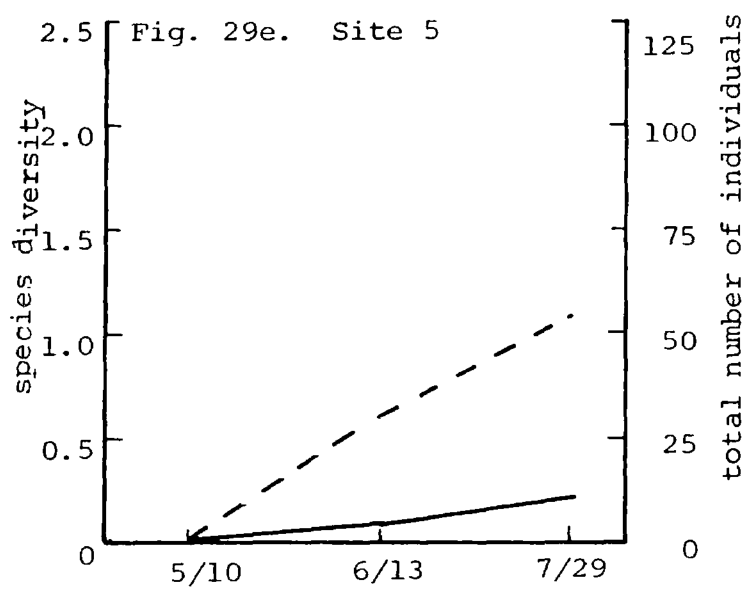


Fig. 29e. Site 5

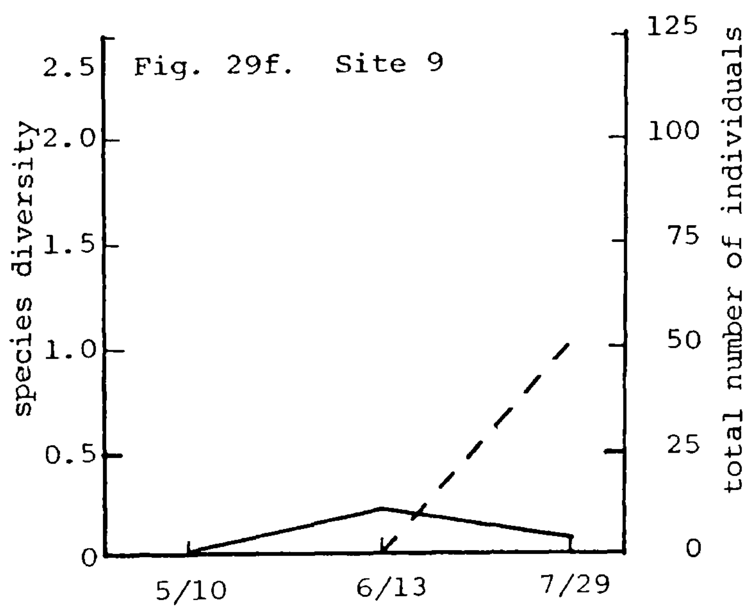


Fig. 29f. Site 9

total number of individuals ——————
species diversity - - - -

Diversity and total numbers at station 4 appear to be affected by the channelization of this section and the impoundment above this station (Figure 29c). The pattern illustrates a fluctuating ecosystem in an immature or stress state. Diversity increased during the first two sampling periods with total numbers also increasing slightly. In July, however, species diversity decreased with a substantial increase in the total numbers of individuals. This illustrates a few residents contributing the majority of the population.

Polluted stations. When diversity indices were compared to total numbers of individuals at station 5, an equally distributed, low population were found (Figure 29f). This situation is not one found in organically polluted waters where a few species (causing low diversity) exist but in high densities. Waters polluted by a toxic substance can affect the macroinvertebrate population by not only decreasing the number of species but also reducing the number of individuals within these species. The effect of the toxic substance can limit these populations by direct toxicity as well as modifying the behavior of the individuals through physiological changes which prevent reproduction or by providing an inadequate diet. Skidmore (1964) concluded resistance of fish to heavy metals is dependent on acclimatization, development of a new phase in their life history, or survival of a resistant group by selective mortality.

Station 9 exhibited a similar pattern as station 5 but diversity indices could only be calculated for the last sample (Figure 29f). Total numbers of individuals were highest in June but they were all from one species. The waters at station 9 were able to be inhabited by a few species but reproduction does not appear to be occurring.

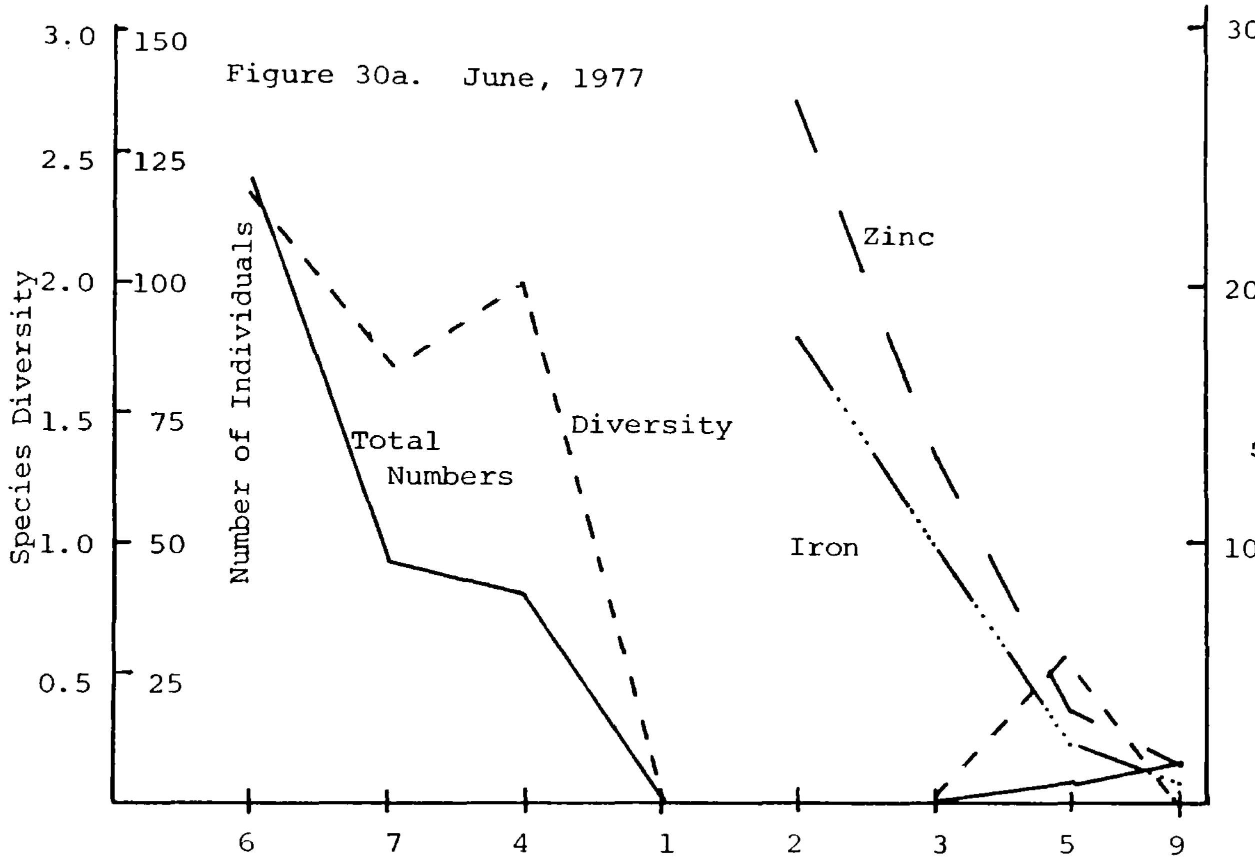
Heavy Metals and Community Diversity

The benthic macroinvertebrate populations in June and July were compared with concentrations of dissolved zinc (mg/l) and total iron (mg/l sediment) analyzed at each station during these two months. Total numbers of individuals and diversity indices of benthic macroinvertebrates were both inversely correlated with dissolved zinc and total iron concentrations (Figure 30a and b).

Stations 6, 7, and 4, the unpolluted stations, had the greatest number of total individuals and the highest diversity indices. Except for zinc concentrations at station 4, zinc and iron concentrations at these three stations were all below the suggested maximum limits for fish and other aquatic life presented by Wentz (1974).

No invertebrates were found at stations 2 or 3 where highest concentrations of zinc and iron were found. Sprague (1965) concluded no macroinvertebrate populations could survive in waters with a concentration of 1.2-2.4 mg/l dissolved zinc and 0.096-0.192 mg/l dissolved copper. Concentrations of copper and zinc at stations 2 and 3 ranged from <0.01-0.01 mg/l and 8.9-27.0 mg/l, respectively.

At station 5 in June, where concentrations of total iron and dissolved zinc were above the suggested maximum limits (Wenta, 1974) but were significantly lower than station 3, there was a slight increase in diversity and total numbers. With a further dilution of these two metals at station 9, the number of individuals increased



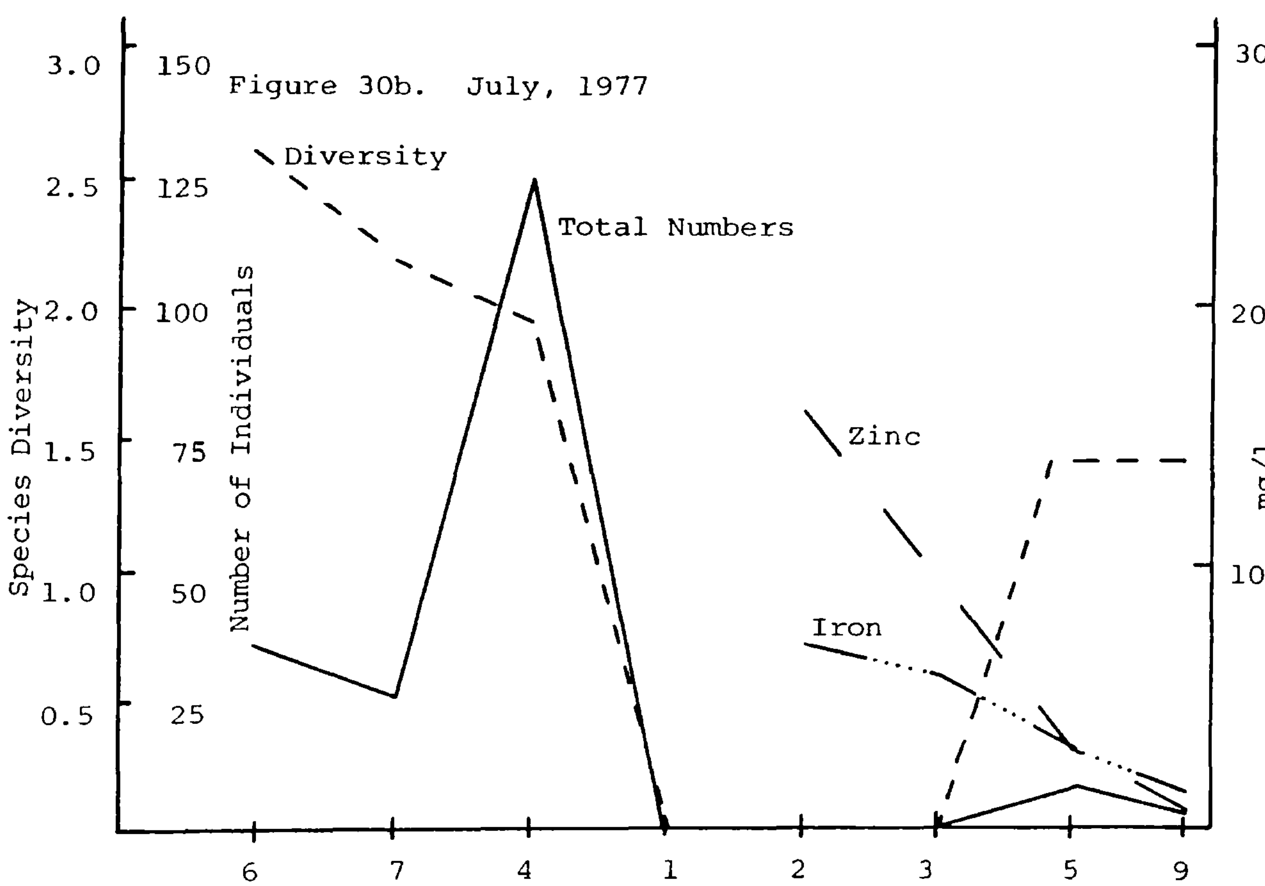


Figure 30a and b. Monthly species diversity and total numbers of benthic macroinvertebrates versus dissolved zinc and total iron (mg/l).

but diversity was zero. At station 5 in July, when zinc remained at a concentration found in June but iron increased slightly, there was an increase in diversity and density (Figure 30b). A decrease in copper was mentioned earlier as a possible reason for this increase at station 5. At station 9, the concentrations of zinc and iron remained at levels found in June but there was a change in the macroinvertebrates. Diversity increased in July but density decreased. The species collected at this station in July could not be considered a resident due to their low population size.

There was no downstream increase in diversity or total numbers of the benthic macroinvertebrates from station 5 to 9 even though concentrations of dissolved zinc and total iron decreased 66% at station 9. It appears, even though a significant decrease in these metals have occurred at station 9, their concentrations still exceed the toxicity threshold, therefore not permitting the macroinvertebrate population to recover. The insects that are able to survive at dissolved zinc and total iron concentrations of 1.5 and 0.71 mg/l, respectively, were also able to tolerate these metals in concentrations up to 3.5 mg/l.

The effect of total iron to macroinvertebrate populations is one of sedimentation rather than toxicity. The ferric iron precipitate cements the bottom of streams, thereby destroying habitat. Mackenthum (1969) reported, in streams affected by gold dredging, decreased production of fish food organisms nearly to zero in the zone of heaviest siltation and the effect extended for a distance of 20 miles. Cordone and Kelley (1961) found bottom fauna to be reduced from 434 individuals per foot^2 to 32 individuals per foot^2 in an area affected by sediment from a hard rock mining operation in California. They also found a change in the species present in areas affected by silt. Trichopteran larvae and nymphs of several Plecoptera and Ephemeroptera disappeared and members of the Chironomidae replaced them. Rouse (1972) concluded even if organisms could tolerate the heavy metal concentrations, there would be no suitable habitat due to the ferric hydroxide precipitate.

CHAPTER V

CONCLUSIONS AND SUMMARY

Acid mine drainage from the abandoned hard rock mines in the headwater tributaries of the Blackfoot River have persisted since the last ore was extracted in 1964. The Mike Horse Mine, on the Mike Horse Creek, has been recognized as the major source of acid mine drainage in the headwater area. An investigation to determine the effects of this pollution on the aquatic communities of Anaconda and Beartrap Creek, and its tributary, Mike Horse Creek, was begun in May, 1977. Physiochemical data, benthic algal species and primary productivity, and benthic macroinvertebrate diversity were examined to measure the stress on the aquatic ecosystem.

The chemical and physical consequences of acid mine drainage occur when pyrite is exposed to dissolved oxygen in water causing the pH to be lowered, dissolved metals to increase, and a ferric hydroxide precipitate to form. An attempt to delineate the specific significance of each of these changes was a major objective of this study.

The majority of previous investigators of acid mine streams have attributed adverse changes in the aquatic ecosystem to the decrease in pH and respective increase in acidity. There is a lack of supportive evidence to this conclusion, because of inadequate heavy metal analysis of these polluted waters. Increased specific conductivity, hardness, and sulfate are considered characteristic of acid mine drainage but their biological meaning has not been determined.

Significantly higher concentrations of sulfate, hardness, and specific conductivity were recorded in the six polluted stations (1,2,3,5,9, and the seep) affected by the Mike Horse Mine effluent. Total and dissolved cadmium, copper, iron, and zinc were also considerably higher at these stations when compared to the levels found at the three control stations (4,6, and 7). A noticeable decrease in these constituents was observed as distance from the Mike Horse Mine increased. The mine was the only detectable source of these increased concentrations in the drainage.

Consistently, total iron and dissolved zinc were the metals found in highest concentrations throughout the polluted stations and were substantially above the maximum suggested limits for fish and other aquatic organisms. Although copper and cadmium were also in excess of these limits, it is impossible to define the synergistic effects between these two metals and zinc because zinc concentrations were so much greater than the respective cadmium and copper concentrations. Dissolved zinc concentrations alone would create an environment suitable only for extremely tolerant species of algae or macroinvertebrates.

It was possible to distinguish six categories of benthic algal species according to their resistance to dissolved zinc and total iron. These categories, however, are only indicative to the specific situation occurring in the Blackfoot headwater area, and therefore, they cannot be designated as indicator species of mining pollution in general. This list can only serve as verification of published habitat preference for species in waters polluted by zinc or acid mine drainage, however. Achnanthes microcephala var. microcephala and Eunotia tenella were found to be very resistant to zinc and iron during this study. These findings substantiate previous investigations which indicate these species may be good indicators of zinc and acid mine pollution.

Chlorophyta was the only phylum represented at the first two stations 0.3-0.7 km below the mine (2 and 3) and species from the Baccilariophyceae occurred at downstream stations (5 and 9) and the stations not directly affected by the mine (station 1 and the seep). Species from the Ulotrichales, Spirogyrales, and Microsporales were well represented at these stations and have been well documented with respect to their tolerance to zinc and/or acid mine drainage. Again, increased distance from the mine and subsequent decrease in zinc, copper, cadmium, and iron, caused an increase in the benthic algal species. Twelve species of benthic algae were collected at the station furthest downstream from the mine, which was a significant increase when compared with the one species collected directly below the effluent. Twenty-three species were tabulated at the control stations of which only four were common to the lower polluted sites. It is apparent the recovery observed at the polluted stations has not been normalized with respect to the control stream and is still under the influence of the acid mine waters.

Highest primary productivity was consistently recorded at station 4. This enhancement was specifically due to the dam above this station which resulted in an increase in nutrients as well as a constancy in flow which prevented scouring during runoff. The two control stations, 6 and 7, were characterized by a lower productivity with a higher species diversity. The pattern established was typical of mountain streams where available nutrients are low and are readily tied up in the algal biomass.

Primary productivity reacted similarly to algal diversity with respect to distance from the mine--the first two stations below the mine were virtually devoid of primary producers. Average levels found at the lowest downstream station, however, were actually greater than those of the control stations, 6 and 7. Typically, if the substance introduced into a watershed is generally toxic, only a few (in this case, one) species will inhabit the area and usually in extremely low populations. As the toxicity becomes diluted by unpolluted waters, an increase in tolerant species occurs which are capable of becoming abundant due to low competition for the available nutrients and limited grazing by higher organisms.

A significant increase in primary productivity at the downstream polluted stations (5 and 9) occurred by the later sampling periods but no dramatic decrease in the concentrations of zinc or iron accompanied this phenomenon. The species at these two stations were the loosely attached filamentous forms, holding their position by either becoming snagged on a sharp rock or twig or caught in an eddy. An increase in discharge would drastically increase scouring and cause washout of these filamentous forms. With a decrease in flow, after runoff, an increase in radiant energy and temperature, optimum conditions for these tolerant species would exist. It can be concluded the species occurring at stations 5 and 9 inhabited these areas because of their tolerance to high concentrations of zinc and iron rather than their ability to maintain their position under running water conditions.

A seep in the Mike Horse drainage, affected by high concentrations of dissolved zinc and copper but characterized by the absence of ferric hydroxide precipitate provided conditions whereby the effect of substrate modification by the precipitate can be separated from the phytotoxic effect of heavy metals. This simple but selective environment created by emergent ground water, supported a rich primary productivity, maintained by four tolerant species, and was second only to the productivity found at station 4. Although zinc and copper concentrations at the seep were two to four times greater than those found at stations 5 and 9, primary productivity was considerably higher at the former. Total number of algal species, however, were consistently lower at the seep than the two downstream stations. Conclusively, the heavy metal concentrations control the number of species able to tolerate a specific concentration while the ferric hydroxide precipitate regulates the subsequent production of these resistant species. The precipitate reduces the biomass by preventing secure attachment of the filaments to the substrate, reducing radiant energy received by the plant, and decreasing the gas exchange between the algal cell and the water.

In contrast to the algae community, the benthic macroinvertebrate population did not exhibit a similar recovery at the polluted stations.

The first two stations below the mine were devoid of macroinvertebrates. Species from the Diptera (Chironomidae) and Plecoptera (*Nemoura* and *Alloperla*) were collected at the downstream polluted stations (5 and 9) but in such small numbers, their permanence in these waters was doubtful. The metal concentrations allow for individuals to survive in the downstream polluted waters but were unable to actively reproduce. This may be a result of the level of the heavy metals creating a behavioral or physiological change which prevents reproduction.

The species diversity at station 5 was actually higher than the furthest downstream station although zinc and iron concentrations were greater at the former. This apparent "recovery" was more likely a phenomenon of drift caused by the close proximity of an unpolluted station above station 5.

The problems facing the macroinvertebrate populations in acid mine waters include being able to tolerate toxic concentrations of metals, finding an adequate food supply, and a suitable habitat. The few species found at the downstream polluted sites have been recognized to tolerate not only heavy metals and/or acid mine drainage but had adapted for a burrowing, silty habitat or loose filamentous algae. These were the only habitats available at the lower stations.

In conclusion, a decrease in pH does not directly control the biota of the headwater streams of the Blackfoot River. It may be used as an indicator of increased solubility of heavy metals or a factor in creating the smothering iron precipitate, but alone, is biologically meaningless in these streams. The toxic concentrations of zinc and total iron (index of ferric hydroxide precipitate) were the two parameters that were most positively correlated to the decrease in aquatic biota in the headwater area.

Ecologically, the acid mine drainage from the Mike Horse Mine only allows the tolerant primary producers to successfully inhabit these waters. Whether the concentrations of dissolved metals creates a toxic environment or the ferric hydroxide precipitate destroys all suitable habitat, no secondary production exists in the headwaters of the Blackfoot River which are polluted from the effluent of the mine. The question of which of these two parameters is controlling the secondary productivity is purely academic. If the Mike Horse Mine was reclaimed properly, both of these negative impacts would be eliminated.

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APPENDIX A

Chemical and Physical Analysis of the Mike Horse Mine

Water Parameter	5/23/77	6/6/77	6/21/77	7/29/77	9/3/77
Arsenic-dissloved		0.002		0.003	
Arsenic-total recoverable		0.008		0.009	
Cadmium-dis		0.028		0.035	
Cadmium-TR		0.030		0.035	
Copper-dis		0.06		0.05	
Copper-TR		0.14		0.14	
Iron -dis		21.0		2.8	
Iron -TR		26.0		7.6	
Lead -dis		0.05		0.05	
Lead -TR		0.05		0.05	
Zinc -dis		38.0		20.0	
Zinc -TR		39.0		21.0	
Dissolved Oxygen	6.0	5.9		5.4	5.5
pH	5.9	6.1		6.2	6.6
Specific Conductivity(hos/cm)	510	500		820.0	
Temperature °C	6.0	7.0		10.0	8.0
Discharge(cms)	0.29	0.30	0.24	0.06	
Velocity(cm/s)	26.9	27.8	35.4	23.9	